Package: fruclimadapt (via r-universe)

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Type Package

Title Evaluation Tools for Assessing Climate Adaptation of Fruit Tree Species

Version 0.4.6

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Description Climate is a critical component limiting growing range of plant species, which also determines cultivar adaptation to a region. The evaluation of climate influence on fruit production is critical for decision-making in the design stage of orchards and vineyards and in the evaluation of the potential consequences of future climate. Bio- climatic indices and plant phenology are commonly used to describe the suitability of climate for growing quality fruit and to provide temporal and spatial information about regarding ongoing and future changes. 'fruclimadapt' streamlines the assessment of climate adaptation and the identification of potential risks for grapevines and fruit trees. Procedures in the package allow to i) downscale daily meteorological variables to hourly values (Forster et al (2016) <doi:10.5194/gmd-9-2315-2016>), ii) estimate chilling and forcing heat accumulation (Miranda et al (2019) <https://ec.europa.eu/eip/agriculture/sites/default/files/fg30_mp5_phenology_critical_temperatures.pdf>), iii) estimate plant phenology (Schwartz (2012) <doi:10.1007/978-94-007-6925-0>), iv) calculate bioclimatic indices to evaluate fruit tree and grapevine adaptation (e.g. Badr et al (2017) <doi:10.3354/cr01532>), v) estimate the incidence of weather-related disorders in fruits (e.g. Snyder and de Melo-Abreu (2005, ISBN:92-5-105328-6) and vi) estimate plant water requirements (Allen et al (1998, ISBN:92-5-104219-5)).

Depends R (>= 3.5.0)

Imports data.table, magrittr, dplyr, zoo, lubridate

License GPL (>= 3)

Encoding UTF-8

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Repository https://carm1r.r-universe.dev

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Contents

`Bigtop_reqs` *Chill and heat requirements for Big Top nectarine*

Description

Chill and forcing heat requirements for the phenological stages between 'bud swelling' (B, 51 in Baggliolini and BBCH scales, respectively) and 'ovary surrounded by dying sepal crown' (I, 72) in Big Top nectarine. For use in combination with the example dataset Tudela_DW.

Usage

```
data("Bigtop_reqs")
```

Format

A data frame with 7 observations on the following 2 variables.

`Creq` a numeric vector, chill portions

`Freq` a numeric vector, forcing heat as growing degree hours

Details

Chill requirements are in chill portions, starting chill accummulation on 1 november (day of year 305), forcing heat is as growing degree hours calculated with linear method with a base temperature of 4.7 C and no optimal and upper critical thresholds.

Source

Miranda C, Santesteban LG and Royo JB. 2013. Evaluation and fitting of models for determining peach phenological stages at a regional scale. Agric Forest Meteorol 178-179: 129-139.

`bioclim_hydrotherm` *Calculation of hydrothermal viticultural indices (Branas, Dryness Index)*

Description

This function calculates the hydrotermic index of Branas, Bernon and Levandoux (BBLI, Branas et al 1946) and the Dryness index (Riou et al 1994).

Usage

```
bioclim_hydrotherm(climdata, lat, elev)
```

Arguments

climdata	a dataframe with daily weather data, including temperature Required columns are Year, Month, Day, Tmax, Tmin and Prec. Optional columns are RHmax, RHmin, Rad and u2med.
lat	the latitude of the site, in decimal degrees. Use positive values for Northern latitudes and negatives for Southern.
elev	the elevation of the site, in meters above sea level.

Details

The BBLI takes into account the influence of both temperature and precipitation on grape yield and wine quality. This index is the sum of the products of monthly mean temperature (Tmean, in Celsius) and monthly accumulated precipitation amount (Prec,in mm) during the April to September season (Northern Hemisphere) or October to February (Southern Hemisphere).

The Dryness index (DI) is measured based on an adaptation of the potential water balance of the soil index of Riou (Riou et al., 1994), developed specially for vineyard use. It enables the characterization of the water component of the climate in a grape-growing region, taking into account the climatic demand of a standard vineyard, evaporation from bare soil, rainfall without deduction for surface runoff or drainage. It indicates the potential water availability in the soil, related to the level of dryness in a region (Tonietto and Carbonneau, 2004). The index uses potential evapotranspiration calculated here with the Penman Monteith method.

Minimum data requirements to calculate the indices are daily temperatures (maximum and minimum temperatures, Tmax and Tmin) and rainfall (l m-2), whereas relative humidity (RHmax and RHmin, %), solar radiation (Rad, MJ m-2 day-1) and mean wind speed at 2m height (u2med,m s-1) are optional. If missing, the function integrates FAO56 (Allen et al 1998) estimations for solar radiation and vapor pressure (air humidity) from daily temperatures. If there is no information available on wind speed, the function assumes a constant value of 2 m s-1.

Value

dataframe with the values of the indices for each season in the climdata file.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations Branas J, Bernon G, Levadoux L. 1946. Elements de Viticulture Generale. Imp. Dehan, Bordeaux Riou C, Carbonneau A, Becker N, Caló A, Costacurta A, Castro R, Pinto PA, Carneiro LC, Lopes C, Climaco P, Panagiotou MM, Sotes V,Beaumond HC, Burril A, Maes J, Vossen P. 1994. Le determinisme climatique de la maturation du raisin: application au zonage de la teneur em sucre dans la communaute europenne. Office des Publications Officielles des Communautes Europennes: Luxembourg, 322pp.

Tonietto J, Carbonneau A. 2004. A multicriteria climatic classification system for grape-growing regions worldwide. Agricultural and Forest Meteorology, 124:81-97.

Examples

```
# Select the appropiate columns from a larger dataset with date information
# in Year, Month, Day format, define the values for the parameters latitude
# and elevation and estimate the hydrotermal indices on each year in the series.
library(magrittr)
library(dplyr)
Weather <- Tudela_DW %>%
   select(Year, Month, Day, Tmax, Tmin, Prec, RHmax, RHmin, Rad, u2med)
elevation <- 314
latitude <- 42.13132
Tudela_BHI <- bioclim_hydrotherm(Weather, latitude, elevation)
```

---

bioclim_thermal *Calculation of bioclimatic viticultural indices focusing on temperature*

Description

This function calculates the Growing Season Average Temperature (GST), the Heliothermal Index (HI) of Huglin, the Winkler (WI) index, the Biologically Effective Degree Day (BEDD) index and the Cool Night (CI) index.

Usage

```
bioclim_thermal(climdata, lat)
```

Arguments

climdata	a dataframe with daily maximum and minimum temperatures. Must contain the columns Year, Month, Day, Tmax, Tmin.
lat	the latitude of the site, in decimal degrees. Use positive values for Northern latitudes and negatives for Southern.

Details

GST index correlates broadly to the maturity potential for grape cultivars grown across many wine regions and provides the basis for zoning viticultural areas in both hemispheres (Hall and Jones, 2009). It is calculated by taking the average of the growing season (April-October in Northern hemisphere, October -April in Southern hemisphere).

HI (Huglin, 1978) is a bioclimatic heat index for viticulture regions using heliothermic potential, which calculates the temperature sum above 10ºC from April until September (Northern hemisphere) or from October until March (Southern hem.). The index takes into consideration daily maximum and average temperature, and slightly modifies the calculated total using the latitude of the location.

WI index (Amerine and Winkler, 1944), also known as growing degree days (GDD) classifies regions based on the accumulation of heat summation units by adding up hours above 10ºC during the growing season.

BEDD index (Gladstones, 1992) is another variant on calculating heat summation which incorporates upper and lower temperature thresholds (accounts for heat accumulation between 10 and 19ºC) and a day length correction similar to HI.

CI index (Tonietto, 1999) takes into account the minimum temperature during grape maturation, which is normally the average minimum air temperature in September/March (Northern or Southern hemispheres, respectively).

Value

data frame with the values of the indices. It contains the columns Year, CI, GST, BEDD, HI, WI

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Amerine MA and Winkler AJ. 1944. Composition and quality of musts and wines of California grapes. Hilgardia 15: 493-675.

Gladstones J. 1992. Viticulture and environment. Winetitles, Adelaide, Australia

Hall A., Jones GV. 2009. Effect of potential atmospheric warming on temperature-based indices describing Australian winegrape growing conditions. Aust J Grape Wine Res 15. 97-119.

Huglin P. 1978. Noveau mode d'evaluation des possibilites héliothermiques d'un milieu viticole. In: Proceedings of the Symposium International sur l'ecologie de la Vigne. Ministére de l'Agriculture et de l'Industrie Alimentaire, Contança pp 89-98.

Tonietto J. 1999. Les macroclimats viticoles mondiaux et l'influence du mésoclimat sur la typicité de la Syrah et du Muscat de Hambourg dans le sud de la France: methodologie de carácterisation. Thése Doctorat. Ecole Nationale Supérieure Agronomique, Montpellier, 233pp.

Examples

```
# Select the appropiate columns from a larger dataset with date information
# in Year, Month, Day format, and estimate indices on each year in the series.
library(magrittr)
library(dplyr)
Weather <- Tudela_DW %>%
   select(Year, Month, Day, Tmax, Tmin)
latitude <- 42.13132
Tudela_BTI <- bioclim_thermal(Weather, latitude)
```

`chill_hours` *Calculation of chill hours from hourly temperature data (Weinberger model)*

Description

The function calculates chill hours using the Weinberger (1950), or 0-7.2ºC method. Sums chill hours over winter, with one chill hour accumulated for hourly temperatures between 0 and 7.2°C. This is a classic method but highly inefficient, particularly for warm regions and in climate change scenarios, as it disregards temperature ranges that are now known to contribute to the fulfilment of chilling requirements. For that reason, its use is not recommended, it is offered only for educational purposes (i.e. comparison of model performance) and compatibility with older bibliography.

Usage

```
chill_hours(climdata, Start)
```

Arguments

`climdata`	a dataframe with hourly temperature data. It must contain the columns Year, Month, Day, DOY, Hour, Temp.
`Start`	parameter indicating the day of the year when chill accumulation is supposed to start.

Value

dataframe with the chill accumulated for all the seasons in the dataset. Seasons begin at the start date and end the day before the start date of the following year. It contains the columns Year, Month, Day, DOY and Chill.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Weinberger JH, 1950. Chilling requirements of peach varieties. Proc Am Soc Hortic Sci 56, 122-128.

Examples

```
# Generate hourly temperatures
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_Sel <- Tudela_DW %>% filter(Tudela_DW$Year<=2002)
Tudela_HT <- hourly_temps(Tudela_Sel,42.13132)
# Calculate chill as chill hours, starting on DOY 305
```

```
Chill_h <- chill_hours(Tudela_HT,305)
```

`chill_portions` *Calculation of chill portions from hourly temperature data (Dynamic model)*

Description

The function calculates chill portions according to the Dynamic model proposed by Fishman et al. (1987a,b), using the formulas extracted by Luedeling et al (2009) from functions produced by Erez and Fishman (1990), available at the University of California, Agriculture and Natural Resources (UC ANR) website http://ucanr.edu/sites/fruittree/files/49319.xls. To date, chill portions is the best existing model for most growing regions, so chill fulfilment should be calculated preferably using this method, especially when transferring varieties from one region to another, or in studies on climate change.

Usage

```
chill_portions(climdata, Start)
```

Arguments

`climdata`	a dataframe with hourly temperature data. It must contain the columns Year, Month, Day, DOY, Temp.
`Start`	parameter indicating the day of the year when chill accumulation is supposed to start.

Value

dataframe with the chill accumulated for all the seasons in the dataset. Seasons begin at the start date and end the day before the start date of the following year. It contains the columns Year, Month, Day, DOY, Chill

Author(s)

Carlos Miranda, `<carlos.miranda@unavarra.es>`

References

Erez A, Fishman S, Linsley-Noakes GC and Allan P, 1990. The dynamic model for rest completion in peach buds. Acta Horticulturae 276, 165-174.

Fishman S, Erez A and Couvillon GA, 1987a. The temperature dependence of dormancy breaking in plants - computer simulation of processes studied under controlled temperatures. Journal of Theoretical Biology 126, 309-321.

Fishman S, Erez A and Couvillon GA, 1987b. The temperature dependence of dormancy breaking in plants - mathematical analysis of a two-step model involving a cooperative transition. Journal of Theoretical Biology 124, 473-483.

Luedeling E, Zhang M, Luedeling V and Girvetz EH, 2009. Sensitivity of winter chill models for fruit and nut trees to climatic changes expected in California's Central Valley. Agriculture, Ecosystems and Environment 133, 23-31.

Examples

```
# Generate hourly temperatures
library(magrittr)
library(dplyr)
library(lubridate)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year<=2002)
Tudela_HT <- hourly_temps(Weather,42.13132)
# Calculate chill as chill portions, starting on DOY 305
Chill_p <- chill_portions(Tudela_HT,305)
```

---

chill_units — *Calculation of chill units from hourly temperature data (Utah model)*

Description

The function calculates chill units using the Utah model (Richardson et al, 1974). This model is characterized by differential weighting of temperature ranges, including negative weights for temperatures above 15.9°C. This model recognizes that different temperatures vary in effectiveness in accumulating chill as well as a negative influence of high temperatures on previously accumulated chill. Chill Units (Utah or Anderson model) perform better than chill hours for a wider range of climates, and it could be considered as the 'reference' method nowadays, but it is ill-suited for warm or Mediterranean conditions. To date, Chill portions is the best existing model for most growing regions, so chill fulfilment should preferably be calculated using that method, especially when transferring varieties from one region to another, or in studies on climate change.

Usage

```
chill_units(climdata, Start)
```

Arguments

`climdata`	a dataframe with hourly temperature data. It must contain the columns Year, Month, Day, DOY, Temp.
`Start`	parameter indicating the day of the year when chill accumulation is supposed to start.

Value

dataframe with the chill accumulated for all the seasons in the dataset. Seasons begin at the start date and end the day before the start date of the following year. It contains the columns Year, Month, Day, DOY, Chill

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Richardson EA, Seeley SD and Walker DR, 1974. A model for estimating the completion of rest for Redhaven and Elberta peach trees. HortScience 9, 331-332.

Examples

```
# Generate hourly temperatures
library(magrittr)
library(dplyr)
library(lubridate)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year<=2002)
Tudela_HT <- hourly_temps(Weather,42.13132)
# Calculate chill as chill units, starting on DOY 305
Chill_u <- chill_units(Tudela_HT,305)
```

---

color_potential — *Evaluation of weather conditions for anthocyanin formation in apple skin*

Description

This function estimates the number of days that can be considered as highly favorable or unfavorable for anthocyanin accumulation in the skin of red apple cultivars during a user defined pre-harvest period (30 days by default). A highly favorable day (Cool day) is considered when the daily maximum temperature is below 26ºC, a highly unfavorable day (Hot day) when the minimum temperature is above 20ºC (Lin-Wang et al, 2011). It also calculates an empirical index in which daily thermal amplitude is corrected to account for the effective range of temperatures for anthocyanin accumulation in the skin (TA_cef). The index considers that daily temperatures above 26ºC are increasingly less favorable for anthocyanin formation, and thus calculates a corrected maximum temperature using a linear function up to 35ºC, where it is left constant at a value of 16, so that the adjusted daily thermal amplitude for Tmax>26ºC is smaller than the observed. The average of maximum and minimum temperatures during the same period is also provided. The function allows testing for several harvest dates.

Usage

```
color_potential(climdata, harvest, span = 30)
```

Arguments

`climdata`	a dataframe with daily maximum and minimum temperatures. Must contain the columns Year, Month, Day, Tmax, Tmin.
`harvest`	a vector with expected harvest days (expressed as day of the year)
`span`	the period (in days) before harvest that will be analyzed. By default, this parameter is set in 30 days.

Value

dataframe with the number of highly favorable (Cool_d) and unfavorable (Hot_d) days for apple red color, as well as the sums of the observed (TA_obs) and effective (TA_cef) daily thermal amplitudes. The average of the maximum (Tmax_avg) and minimum (Tmin_avg) temperatures for each year (Year) in the series during the 30 days previous to each harvest date (Day_h) is also provided.

Author(s)

Carlos Miranda, `<carlos.miranda@unavarra.es>`

References

Lin-Wang K, Micheletti D et al, 2011. High temperature reduces apple fruit colour via modulation of the anthocyanin regulatory complex. Plant, Cell and Environment 34, 1176-1190.

Examples

```
# Select the appropiate columns from Tudela_DW example dataset, create
# a vector or harvest dates and estimate the number favorable and
# unfavorable days on each year in the dataset.
library(magrittr)
library(dplyr)
Weather <- Tudela_DW %>%
   select(Year, Month, Day, Tmax, Tmin) %>%
   filter (Tudela_DW$Year<=2002)
harvest <- c(225, 250, 275)
Color_assess <- color_potential(Weather, harvest)
```

`coolness_index` *Calculation of night coolness index*

Description

This function calculates a night coolness index based in the Cool Night index of Tonietto (1999). Instead of calculating the mean of minimum temperatures in September/March (Northern or Southern hemispheres, respectively), this function allows to define the harvest date and the number of days that will be analyzed (by default, 30 days), and calculates the mean of minimum temperatures in the in the specified period of days before harvest. The function allows testing for several harvest dates simultaneously.

Usage

```
coolness_index(climdata, harvest, span = 30)
```

Arguments

climdata	a dataframe with daily maximum and minimum temperatures. Must contain the columns Year, Month, Day, Tmax, Tmin.
harvest	a vector with expected harvest days (expressed as day of the year)
span	the period (in days) before harvest that will be analyzed. By default, this parameter is set in 30 days.

Value

dataframe with the values of the indices. It contains the columns Year, Harvest, Coolness

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Tonietto J. 1999. Les macroclimats viticoles mondiaux et l'influence du mésoclimat sur la typicité de la Syrah et du Muscat de Hambourg dans le sud de la France: methodologie de carácterisation. Thése Doctorat. Ecole Nationale Supérieure Agronomique, Montpellier, 233pp.

Examples

```
# Select the appropiate columns from the Tudela_DW example dataset,
# create a vector or harvest dates and estimate the coolness index
# for the 30 days prior to harvest on each year in the dataset.
library(magrittr)
library(dplyr)
Weather <- Tudela_DW %>%
   select(Year, Month, Day, Tmax, Tmin) %>%
   filter (Tudela_DW$Year<=2002)
harvest <- c(225, 250, 275)
coolness <- coolness_index(Weather, harvest)
```

Dates_BT *Example phenological dates for Big Top nectarine in Tudela*

Description

Estimated dates (as day of the year, DOY) for bloom, early fruit growth stages and harvest for Big Top Nectarine in Tudela (2001-2010). Dates have been estimated using the functions included in this package.

Usage

```
data("Dates_BT")
```

Format

A data frame with 10 observations on the following 6 variables.

`Year` a numeric vector, the year of the observation

`sbloom` a numeric vector, beggining of bloom as DOY

`ebloom` a numeric vector, end of bloom as DOY

`Start_ing` a numeric vector, beggining of early growth stage as DOY

`End_ing` a numeric vector, end of early growth stage as DOY

`Harvest` a numeric vector, harvest date as DOY

`DTR` *Calculation of the diurnal temperature range (DTR)*

Description

This function calculates the mean diurnal temperature range (DTR) for a custom period. Mean DTR is obtained by subtracting the daily minimum temperature (Tmin) from daily maximum temperature (Tmax) and then averaged for the period defined by the user, provided as the initial (init) and end (end) date expressed as days of the year. The function requires the initial and end dates to be in the same year.

Usage

```
DTR(climdata, init_d, end_d)
```

Arguments

`climdata`	a dataframe with daily maximum and minimum temperatures. Must contain the columns Year, Month, Day, Tmax, Tmin.
`init_d`	the initial date (as day of the year) of the evaluation period
`end_d`	the end date (as day of the year) of the evaluation period

Value

dataframe with the value of DTR for each year in the series. It contains the columns Year, First_d, Last_d, DTR

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

Examples

```
# Select the appropiate columns from the Tudela_DW example dataset,
# and estimate the mean DTR for July on each year in the dataset.
library(magrittr)
library(dplyr)
Weather <- Tudela_DW %>%
   select(Year, Month, Day, Tmax, Tmin)
DTR_July <- DTR(Weather, 182, 212)
```

ET_penman *Calculation of daily potential evapotranspiration by Penman (1948) method*

Description

This function calculates the potential evapotranspiration (ETref) using daily weather data and the Penman (1948) method

Usage

```
ET_penman(climdata, lat, elev)
```

Arguments

`climdata`	a dataframe with daily weather data. Must contain the columns Year, Month, Day, Tmax, Tmin, RHmax, RHmin, Rad, u2med.
`lat`	the latitude of the site, in decimal degrees.
`elev`	the elevation of the site, in meters above sea level.

Details

This version of the function requires the user to supply in weather data daily values for temperature (Tmax and Tmin), relative humidity (RHmax and RHmin), solar radiation (Rad in MJ m-2 day-1) and mean wind speed at 2m height (u2med in m s-1).

Value

dataframe where Date, DOY and ET columns have been added to the ones in climadata data frame.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Penman HL 1948.Natural evaporation from open water, bare soil and grass. Proc. R. Soc. Lond. 193:120–145.

Examples

```
 # Calculate ET by Penman method in the Tudela_DW example dataset
data(Tudela_DW)
library(magrittr)
library(dplyr)
elevation <- 314
latitude <- 42.13132
ET_Penman <- ET_penman(Tudela_DW, elevation, latitude)
```

ET_penman_monteith *Calculation of daily reference evapotranspiration by Penman-Monteith method*

Description

This function calculates the reference evapotranspiration (ETref) for short (ETos) and tall (ETrs) canopies using daily weather data. The method is based on the FAO56 guidelines (Allen et al, 1998) and on the standardized Penman Monteith equation from the Environmental Water Resources Institute of the American Society of Civil Engineers (Allen et al, 2005).

Usage

```
ET_penman_monteith(climdata, lat, elev)
```

Arguments

climdata	a dataframe with daily weather data. Required columns are Year, Month, Day, Tmax and Tmin. Optional columns are RHmax, RHmin, Rad and u2med.
lat	the latitude of the site, in decimal degrees.
elev	the elevation of the site, in meters above sea level.

Details

Minimum data requirements to calculate ET are daily temperatures (maximum and minimum temperatures, Tmax and Tmin), whereas relative humidity (RHmax and RHmin), solar radiation (Rad, MJ m-2 day-1) and mean wind speed at 2m height (u2med,m s-1) are optional. If missing, the function integrates FAO56 estimations for solar radiation and vapor pressure (air humidity) from daily temperatures. If there is no information available on wind speed, the function assumes a constant value of 2 m s-1.

Value

dataframe with Year, Month, Day, DOY, ETos and ETrs values.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations

Allen RG, Walter IA, Elliott RL, Howell TA, Itenfisu D, Jensen ME, Snyder RL 2005. The ASCE standardized reference evapotranspiration equation. Reston, VA:American Society of Civil Engineers. 59 p.

Examples

```
# Calculate ET by Penman-Monteith method in the Tudela_DW example dataset
library(magrittr)
library(dplyr)
elevation <- 314
latitude <- 42.13132
ET_PM <- ET_penman_monteith(Tudela_DW, latitude, elevation)
```

GDD_linear *Calculates growing degree days (GDD) using a linear method*

Description

The function calculates the daily heat unit accumulation (GDD) from daily temperature data with a linear method based on averaging the daily maximum and minimum temperatures (Arnold, 1960). GDD are calculated by subtracting the plant's lower base temperature (Tb) from the average daily air temperature. The user can define an upper temperature threshold (Tu) so that all temperatures above Tu will have equal value in GDD summation.

Usage

```
GDD_linear(Temp_Day, Tb, Tu = 999)
```

Arguments

`Temp_Day`	a dataframe of daily temperatures. This data frame must have a column for Year, Month, Day, and daily minimum (Tmin) and maximum (Tmax) temperatures.
`Tb`	the base temperature required to calculate GDD.
`Tu`	an optional upper temperature threshold.

Value

dataframe consisting of the columns Year, Month, Day, Tmax, Tmin, Tmean and GDD.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Arnold, C.Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc.Amer. Soc. Hort. Sci. 76:682–692.

Examples

```
# Calculate GDD in the example dataset using 4.5ºC as base temperature and no
# upper threshold.
library(magrittr)
library(dplyr)
GDD <- GDD_linear(Tudela_DW,4.5)
# Calculate GDD in the example dataset using 4.5ºC as base temperature and an
# upper threshold at 25ºC.
GDD <- GDD_linear(Tudela_DW,4.5,25)
```

GDH_asymcur *Calculates growing degree hours (GDH) using ASYMCUR method*

Description

The function calculates the daily heat unit accumulation (GDH) from hourly temperature data, using the ASYMCUR model proposed by Anderson et al (1986). The model is a refinement of the linear model proposed by Anderson and Seeley (1992) defined by a base, optimum and critical temperature. Heat accumulation begins when temperatures are above a minimum (base temperature, Tb), and growth increases with temperature up to a point (optimum temperature, Topt) at which there is no longer an increase. The critical temperature (Tcrit) is the temperature above which growth ceases. The difference of ASYMCUR model with the linear by Anderson and Seeley (1992)is that the former uses an asymmetric curvilinear relationship to model GDH accumulation. The function allows the user to define Tb, Topt and Tcrit, and uses as default the values set by Anderson et al (1986) for fruit trees: Tb=4ºC, Topt=25ºC and Tcrit=36ºC.

Usage

```
GDH_asymcur(Hourdata, Tb = 4, Topt = 25, Tcrit = 36)
```

Arguments

`Hourdata`	a dataframe of hourly temperatures. This data frame must have a column for Year, Month, Day, DOY (day of year), Hour, Temp (hourly temperature).
`Tb`	the base temperatures to calculate GDH
`Topt`	the optimal temperatures to calculate GDH
`Tcrit`	the critical temperature

Value

dataframe with daily data. It contains the columns Date, Year, Month, Day, DOY (day of the year), and GDH

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Anderson JL, Richardson EA and Kesner CD, 1986. Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. Acta Horticulturae 184, 71-75. Anderson JL and Seeley SD, 1992. Modelling strategy in pomology: Development of the Utah models. Acta Horticulturae 313, 297-306.

Examples

```
# Generate hourly temperatures for the example dataset
library(magrittr)
library(dplyr)
library(lubridate)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year==2003)
Tudela_HT <- hourly_temps(Weather,42.13132)
# Calculate GDH using default threshold temperatures
GDH_default <- GDH_asymcur(Tudela_HT)
# Calculate GDH using as custom set temperature thresholds
# Tb=4.5, Topt=22 and Tcrit=32
GDH_custom <- GDH_asymcur(Tudela_HT, 4.5, 22, 32)
```

GDH_linear — *Calculates growing degree hours (GDH) using a linear method*

Description

The function calculates the daily heat unit accumulation (GDH) from hourly temperature data, using a standard linear model or the linear model proposed by Anderson and Seeley (1992). The standard model is defined by a base temperature, and the Anderson and Seeley (1992) includes also optimum and critical temperatures. In both variants, heat accumulation begins when temperatures are above a minimum (base temperature, Tb), and growth increases linearly with temperature. In the Anderson and Seeley (1992) variant, growth no longer increases once the optimum temperature (Topt) is reached, meaning that GDH above it are constant. The critical temperature (Tcrit) is the temperature above which growth ceases (i.e. GDH=0). The function allows the user to define Tb, Topt and Tcrit, and uses as default the values set by Anderson et al (1986) for fruit trees: Tb=4ºC, Topt=25ºC and Tcrit=36ºC. In the standard linear model with upper thresholds, use Topt = 999 and Tcrit = 999.

Usage

```
GDH_linear(Hourdata, Tb = 4, Topt = 25, Tcrit = 36)
```

Arguments

Hourdata	a dataframe of hourly temperatures. This data frame must have a column for Year, Month, Day, DOY (day of year),Hour, and Temp (hourly temperature).
Tb	the base temperatures to calculate GDH
Topt	an optional optimal temperatures to calculate GDH
Tcrit	an optional critical temperature

Value

dataframe with daily data. It contains the columns Date, Year, Month, Day, DOY (day of the year), and GDH

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Anderson JL and Seeley SD, 1992. Modelling strategy in pomology: Development of the Utah models. Acta Horticulturae 313, 297-306.

Examples

```
# Generate hourly temperatures for the example dataset
library(magrittr)
library(dplyr)
library(lubridate)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year==2003)
Tudela_HT <- hourly_temps(Weather,42.13132)
# Calculate GDH using default threshold temperatures
GDH_default <- GDH_linear(Tudela_HT)
# Calculate GDH using an optimal temperature threshold with
# no critical threshold
GDH_custom <- GDH_linear(Tudela_HT, 4.5, 22, 999)
```

`hourly_RH` *Estimation of the hourly relative humidity on a daily series*

Description

This function estimates the hourly relative humidity (RH), using daily temperature and humidity data. Hourly humidity is estimated with the formula proposed by Waichler and Wigmosta (2003) which require maximum and minimum values of daily temperature and relative humidity.

Usage

```
hourly_RH(climdata, lat)
```

Arguments

`climdata`	a dataframe with daily temperatures and RH for each day in a series. Must contain the columns Year, Month, Day, Tmax, Tmin, RHmax (daily maximum relative humidity) and RHmin (minimum daily relative humidity).
`lat`	the latitude of the site, in decimal degrees.

Value

dataframe with columns Date, Year, Month, Day, DOY, Hour, Temp and RH

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Waichler SR and Wigmosta MS, 2003. Development of hourly meteorological values from daily data and significance to hydrological modeling at H.J. Andrews experimental forest. Journal of Hydrometeorology 4, 251-263.

Examples

```
# Generate hourly relative humidity
library(magrittr)
library(dplyr)
library(lubridate)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year==2003)
Tudela_HRH <- hourly_RH(Weather, 42.13132)
```

hourly_temps *Estimation of hourly temperatures from daily data*

Description

This function generates hourly temperatures from daily maximum and minimum values, using the method proposed by Linvill (1990), which also requires sunset and sunrise calculation for each day in the series. Sunset and sunrise hours for a location are internally estimated using the function solar_times from the latitude and the day of the year (DOY) using the equations by Spencer (1971) and Almorox et al. (2005).

Usage

```
hourly_temps(climdata, latitude)
```

Arguments

climdata	a data frame containing the columns Year, Month, Day, Tmax and Tmin. Data must not contain any gap.
latitude	the latitude of the site, in decimal degrees.

Value

a dataframe containing the columns Date, Year, Month, Day, DOY, Hour, Sunrise (hour of sunrise), Sunset (hour of sunset), Daylength and Temp (hourly temperature).

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Almorox J, Hontoria C and Benito M, 2005. Statistical validation of daylength definitions for estimation of global solar radiation in Toledo, Spain. Energy Conversion and Management 46, 1465-1471.

Linvill DE, 1990. Calculating chilling hours and chill units from daily maximum and minimum temperature observations. HortScience 25, 14-16.

Spencer JW, 1971. Fourier series representation of the position of the Sun. Search 2, 172.

Examples

```
# Generate hourly temperatures
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_HT <- hourly_temps(Tudela_DW,42.13132)
```

hourly_windspeed *Estimation of the hourly wind speed from daily mean data*

Description

This function estimates the hourly wind speed from a dataset with mean daily wind speeds. Hourly wind speeds from daily values are computed using the formulas proposed by Guo et al (2016), using mean daily values (u2med, required) and maximum ones (u2max, optional). If only mean wind values are available, the function uses a modified version of the Guo formula, so that the maximum values are obtained in daytime hours.

Usage

```
hourly_windspeed(climdata)
```

Arguments

climdata	a dataframe with daily wind speed data. Required columns are Year, Month, Day and u2med. u2max is an optional data column.

Value

dataframe with the columns Date, Year, Month, Day, DOY, Hour and u2 (hourly wind speed, m s-1).

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Guo Z, Chang C, Wang R, 2016. A novel method to downscale daily wind statistics to hourly wind data for wind erosion modelling. In: Bian F., Xie Y. (eds) Geo-Informatics in Resource Management and Sustainable Ecosystem. GRMSE 2015. Communications in Computer and Information Science, vol 569. Springer, Berlin, Heidelberg

Examples

```
# Generate hourly wind speed for the example dataset
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_Hu2 <- hourly_windspeed(Tudela_DW)
```

moderate_wind — *Estimation of the daily hours with moderate wind from daily weather data*

Description

This function estimates the daily hours with wind speed equal or above than 'moderate breeze' wind (5.5 m s-1 in the Beaufort scale) from a dataset with daily wind speeds. Hourly wind speeds from daily values are computed using the formulas proposed by Guo et al (2016), using mean daily values (u2med, required) and maximum ones (u2max, optional). If only mean wind values are available, the function uses a modified version of the Guo formula, so that the maximum values are obtained in daytime hours.

Usage

```
moderate_wind(climdata)
```

Arguments

climdata	a dataframe with daily wind speed data. Required columns are Year, Month, Day and u2med. u2max is an optional data column.

Value

dataframe with the columns Date, Year, Month, Day, DOY, and h_wind (hours with wind speed equal or above 5.5 m/s).

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Guo Z, Chang C, Wang R, 2016. A novel method to downscale daily wind statistics to hourly wind data for wind erosion modelling. In: Bian F., Xie Y. (eds) Geo-Informatics in Resource Management and Sustainable Ecosystem. GRMSE 2015. Communications in Computer and Information Science, vol 569. Springer, Berlin, Heidelberg

Examples

```
# Estimate daily hours with wind speed above moderate speeds for the example
# dataset
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_Mu2 <- moderate_wind(Tudela_DW)
```

phenology_sequential *Prediction of phenological stages using a sequential model*

Description

The function predicts phenological phases for a climate series from daily chill and heat requirements and daily chill and forcing heat data. The sequential model used in the function considers that chilling and heat have independent effects. It consists of an accumulation of chill up to the plant requirement, followed by heat up to forcing requirement, with no overlap between both phases. The function is independent of the method used to calculate chill and forcing heat, so that chill can be supplied as chill hours, chill units or chill portions (recommended, particularly for warm climates or in climate change studies), forcing heat accumulation can be supplied either as GDD or GDH. The function allows predicting several stages (or the same for different cultivars), by supplying a dataframe in which each row contains chill and heat requirements for a phenological stage.

Usage

```
phenology_sequential(GDH_day, Reqs, Start_chill)
```

Arguments

`GDH_day`	a dataframe with daily chilling and forcing accumulation. It must contain the columns Year, Month, Day, DOY, Chill, GD.
`Reqs`	a dataframe in which each row contains the chilling and forcing heat requirements of one phenological stage. It must contain the columns Creq (for chilling) and Freq (for forcing heat).
`Start_chill`	parameter indicating the day of the year when chill accumulation is supposed to start.

Value

dataframe with the predicted dates of chilling requirement fulfillment and date of occurrence of each phenological stage defined in Reqs. Columns are Creq and Freq (chilling and forcing heat requirements for the phenological stage), Season, Creq_Year and Creq_DOY (year and day of the year in which chill requirements are fulfilled), Freq_Year and Freq_DOY (year and day of the year of occurrence the phenological stage).

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

Examples

```
data(Tudela_DW)
data(Bigtop_reqs)
library(magrittr)
library(dplyr)
```

```
library(lubridate)
# Select the first two seasons in Tudela_DW example dataset
Tudela_Sel <- Tudela_DW %>%
       filter (Tudela_DW$Year<=2002)
# Generate hourly temperatures from the example dataset
Tudela_HT <- hourly_temps(Tudela_Sel,42.13132)
# Calculate chill as chill portions, starting on DOY 305
Chill <- chill_portions(Tudela_HT,305)
# Calculate forcing heat as growing degree hours (GDH) with the linear model,
# using base temperature 4.7 C and no upper thresholds
GDH <- GDH_linear(Tudela_HT,4.7,999,999)
# Combine Chill and GDH values in a dataframe with a format compatible with
# the function phenology_sequential
Tudela_CH <- merge(Chill,GDH) %>%
  select(Date, Year, Month, Day, DOY, Chill,GDH) %>%
    rename(GD=GDH)
# Obtain the predicted dates using the example dataset with requirements
Phenology_BT <- phenology_sequential(Tudela_CH, Bigtop_reqs, 305)
```

---

phenology_thermal_time

Prediction of phenological stages using a thermal time model

Description

The function predicts phenological phases for a climate series using a certain starting date and forcing heat requirements data. The thermal time model used in the function considers that only heat accumulated from a set date to a given sum explain the date of occurrence of the phenological stage (i.e, it assumes that dormancy release occurs before that date). The function is independent of the method used to calculate forcing heat, so that forcing heat can be supplied either as GDD or GDH. The function allows predicting several stages (or the same for different cultivars), by supplying a dataframe in which each row contains the day for starting forcing and heat requirements for a phenological stage.

Usage

```
phenology_thermal_time(GD_day, Reqs)
```

Arguments

GD_day	a dataframe with daily forcing accumulation. It must contain the columns Year, Month, Day, DOY, GD.
Reqs	a dataframe in which each row contains the start date for forcing and the heat requirements of one phenological stage. It must contain the columns Dreq (the start date) and Freq (the forcing heat requirements).

Value

dataframe with the predicted dates of occurrence of each phenological stage defined in Reqs. Columns are Dreq and Freq (start date and forcing heat requirements for the phenological stage), Season, Dreq_Year and Dreq_DOY (year and day of the year in which forcing begins), Freq_Year and Freq_DOY (year and day of the year of occurrence the phenological stage).

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

Examples

```
# Calculate GDD values from a climate dataset with daily temperature data,
# using a base temperature of 0 C and format it to be compatible with
# phenology_thermal_time
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_GDD <- GDD_linear(Tudela_DW,0) %>% rename(GD=GDD)
# Create a dataframe with start dates and forcing requirements for
# bloom and veraison in the GFV model for 'Chardonnay' (Parker et al,
# 2013, Agric Forest Meteorol 180:249-264) in the format required for
# the function
Dreq <- c(60,60)
Freq <- c(1217,2547)
Chardonnay_reqs <- as.data.frame(cbind(Dreq,Freq))
# Obtain the predicted dates
Phenology_Chardonnay <- phenology_thermal_time(Tudela_GDD,Chardonnay_reqs)
```

---

pollination_weather *Evaluation of weather conditions for pollination on a daily series*

Description

This function estimates the number of days with conditions favorable, unfavorable and moderately favorable for insect pollination of fruit trees during the flowering period using daily weather data.

Usage

```
pollination_weather(climdata, fendata, lat)
```

Arguments

climdata	a dataframe with daily maximum and minimum temperatures, wind speed and precipitation. Required columns are Year, Month, Day, Tmax, Tmin, u2med (daily mean wind speed) and Prec (precipitation). u2max (daily maximum wind speed) is optional.

`fendata` a dataframe with julian day of the beginning (sbloom) and end (ebloom) of the flowering season. Must contain the columns Year, sbloom and ebloom in that order.

`lat` the latitude of the site, in decimal degrees, used to estimate hourly temperatures.

Details

Days are classified considering the classification proposed by Williams and Sims (1977), by accounting the number of favorable hours for pollination within a day. One hour is considered favorable if the temperature is above 12.5 C, the speed of the wind below 4.5 m s-1 and no rainfall occurs (Williams and Sims, 1977; Ramirez and Davenport, 2013). Hourly wind speeds from daily values are computed using the formulas proposed by Guo et al (2016), using mean daily values (u2med, required) and maximum ones (u2max, optional). If only mean wind values are available, the function uses a modified version of the Guo formula, so that the maximum values are obtained in daytime hours. No hourly downscaling of rainfall is performed, the function allow daily rainfall below 2.0 mm when estimating if a day is favorable for pollination or not.

Value

a data frame with the columns Year, Sbloom (bloom start, DOY) , Ebloom (end of bloom, DOY), Bloom_length (in days), Fav_d (number of favorable days), Modfav_d (number of moderately favorable days) and Unfav_d (number of unfavorable days).

Author(s)

Carlos Miranda, `<carlos.miranda@unavarra.es>`

References

Guo Z, Chang C, Wang R, 2016. A novel method to downscale daily wind statistics to hourly wind data for wind erosion modelling. In: Bian F., Xie Y. (eds) Geo-Informatics in Resource Management and Sustainable Ecosystem. GRMSE 2015. Communications in Computer and Information Science, vol 569. Springer, Berlin, Heidelberg

Ramirez F and Davenport TL, 2013. Apple pollination: A review. Scientia Horticulturae 162, 188-203.

Williams RR, Sims FP, 1977. The importance of weather and variability in flowering time when deciding pollination schemes for Cox's Orange Pippin. Experimental Horticulture 29, 15-26.

Examples

```
# Estimate weather conditions during blooming season using the example
# datasets included in the package
library(magrittr)
library(dplyr)
library(lubridate)
Bloom_BT <- Dates_BT %>%
   select(Year, sbloom, ebloom) %>%
   filter(Dates_BT$Year<=2002)
Weather <- Tudela_DW %>%
```

```
  filter (Tudela_DW$Year<=2002)
Pol_weather_BT <- pollination_weather(Weather,Bloom_BT,42.13132)
```

`russet` *Estimation of the russet risk for apple and pear fruits*

Description

This function assesses the risk of russet in fruit skins. The risk is defined by the number of hours with the relative humidity (RH) above a threshold during a given period. For reference, in 'Conference' pear the risk is defined by the number of hours with RH> 75% from 12 to 30 days after full bloom (Alegre, 2013). In 'Golden' apple, the risk is defined by the number of hours with RH> 55% from 30 to 34 days after full bloom (Barcelo-Vidal et al., 2013). The function requires hourly temperatures and humidity, if only daily data is available, the function hourly_RH can be used to estimate them.

Usage

```
russet(climdata, fendata, RH_crit, init_d, end_d)
```

Arguments

`climdata`	a dataframe with hourly temperature and RH data. Required columns are Date, Year, Month, Day, DOY (julian day), Hour and RH.
`fendata`	a dataframe with julian day of occurrence of the full bloom (F2) phenological stage. Must contain the columns Year and Fday in that order.
`RH_crit`	the relative humidity threshold
`init_d`	the initial date (as days after full bloom) of the sensitive period
`end_d`	the end date (as days after full bloom) of the sensitive period

Value

data frame with the number of risk hours (Russet_hours) in the sensitive period for each year in the series.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Alegre S. 2013. Tecnicas de cultivo. In. VII Foro INIA "adaptacion a cambio climatico en la produccion fruticola de hueso y pepita". Madrid, Spain, pp 1-18 Barcelo-Vidal C, Bonany J, Martin-Fernandez JA and Carbo J. 2013. Modelling of weather parameters to predict russet on 'Golden Delicious' apple. J. Hort. Sci. Biotech. 88: 624-630.

Examples

```
# Select the appropiate columns from the example dataset
# Dates_BT and rename column names to make the file compatible
# with the function
library(magrittr)
library(dplyr)
library(lubridate)
Bloom <- Dates_BT %>%
   select(Year, sbloom) %>%
   rename(Fday=sbloom) %>%
   filter(Year==2003)
# Obtain estimated hourly RH from the example dataset Tudela_DW
Weather <- Tudela_DW %>%
        filter (Tudela_DW$Year==2003)
RH_h <- hourly_RH(Weather, 42.13132)
# Estimate the number of russet-inducing days for a RH>55\%
# between 30 to 34 days after full bloom for each season
Russet_Risk <-russet(RH_h,Bloom,55,30,34)
```

---

solar_times *Estimation of the sunrise and sunset hour*

Description

This function estimates the sunrise and sunset hour for a location, characterized by latitude, and the day of the year (DOY). The function uses the equations by Spencer (1971) and Almorox et al. (2005).

Usage

```
solar_times(latitude, DOY)
```

Arguments

`latitude`	the latitude of the site, in decimal degrees.
`DOY`	numeric value or vector specifying the day of the year for which calculations should be done.

Value

list with Sunrise and Sunset times and Daylength.

Note

Code adapted from the function `daylength`, of the chillR Package

References

Almorox J, Hontoria C and Benito M, 2005. Statistical validation of daylength definitions for estimation of global solar radiation in Toledo, Spain. Energy Conversion and Management 46(9-10), 1465-1471

Luedeling E, 2018. chillR: Statistical Methods for Phenology Analysis in Temperate Fruit Trees. R package version 0.70.12. https://CRAN.R-project.org/package=chillR

Spencer JW, 1971. Fourier series representation of the position of the Sun. Search 2(5), 172.

Examples

```
# Create a vector with 365 days in sequence and calculate sunrise and
# sunset hours for that year in a site placed a 45.5 N
Days <- seq(1:365)
Sunrise_Sunset <- solar_times(41.5,Days)
```

---

spring_frost *Calculates the risk of spring frosts for a climate series*

Description

The function evaluates the number of early and spring frosts and the expected frost damage on each season within a climate data series. Frost damage is assumed to be multiplicative, directly related to the minimum temperature and unrelated to the duration of the frost. The function is an enhanced version of the Damage Estimator Excel application program (DEST.xls) created by de Melo-Abreu and Snyder and bundled with FAO Environment and Natural Resources Series 10 manual (Snyder and de Melo-Abreu, 2005). The function compares daily minimum temperature (Tmin) with the critical temperatures (Tcrit) for that day. Daily Tcrit are linearly interpolated from a user-provided dataframe with the day of occurrence of the stages on each season and a vector of critical temperatures (the lethal temperatures for 10% (LT_10) and 90% (LT_90) of the organs) for each phenological stage. The main difference of spring_frost with DEST.xls is that the latter uses the same dates of phenological occurrence for all the years evaluated (up to 50 years of data), while spring_frost is able to use the expected dates of occurrence for each year from historical records or estimations produced by the functions phenology_thermal_time or phenology_sequential, included in this package. There is no limit for the number of years evaluated.

Usage

```
spring_frost(tempdata, fendata, tcrit, lastday = 181)
```

Arguments

`tempdata` a dataframe with daily minimum temperatures for each year in a series. Must contain the columns Year, julian day of year (DOY) and the minimum daily temperature (Tmin).

`fendata` a dataframe with julian day of occurrence of the phenological stages that can be produced by phenology_thermal_time or phenology_sequential functions. Must contain the columns Year, and Pheno_date.

`tcrit` a dataframe with columns LT_10 and LT_90, critical temperatures for all the phenological stages indicated in fendata.

`lastday` the last day (day of the year) to evaluate. By default, lastday = 181 (June 30th).

Details

The last day in the year for the evaluation can be defined by the user, and it is set by default set at DOY 181, to avoid computing autumn and winter frosts.

The function currently works only with phenological dates occurring within the same year.

Value

a list with two data frames. The df Days_frost has the columns Year, DOY, Tmin, Tcrit and Day_Frost (indicates a day of frost with a 1 if Tmin<=Tcrit). The df Damage_frosts indicates the total number of frost days and the expected damage (as % of organs) for every year in the series. It has the columns Year, Frost_d, Damage.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Snyder RL, de Melo-Abreu JP. 2005. Frost Protection: fundamentals, practice and economics (2 volumes). FAO Environment and Natural Resources Service Series, No. 10 - FAO, Rome.

Examples

```
# Generate hourly temperatures from the first season from
# the example dataset Tudela_DW
library(magrittr)
library(dplyr)
library(lubridate)
Tudela_Sel <- Tudela_DW %>% filter(Tudela_DW$Year<=2002)
Tudela_HT <- hourly_temps(Tudela_Sel,42.13132)
# Calculate chill as chill portions, starting on DOY 305
Chill <- chill_portions(Tudela_HT,305)
# Calculate forcing heat as growing degree hours (GDH) with the linear model,
# using base temperature 4.7 C and no upper thresholds
GDH <- GDH_linear(Tudela_HT,4.7,999,999)
# Combine Chill and GDH values in a dataframe with a format compatible with
# the function phenology_sequential
Tudela_CH <- merge(Chill,GDH) %>%
   select(Date, Year, Month, Day, DOY, Chill,GDH) %>%
   arrange(Date) %>%
   rename(GD=GDH)
# Obtain the predicted dates using the example dataset with the requirements
```

```
# indicated in the Bigtop_reqs example dataset and create a dataframe with a
# format compatible with the function spring_frost
Phenology_BT <- phenology_sequential(Tudela_CH, Bigtop_reqs, 305) %>%
   select(Freq_Year,Freq_DOY) %>%
   rename(Year=Freq_Year,Pheno_date=Freq_DOY) %>%
   filter (Year==2002)
# Create a dataframe with daily minimum temperatures with the
# format required by spring_frost
Tmin_Tudela <- Tudela_Sel %>% filter(Year==2002) %>%
  mutate(Date=make_date(Year,Month,Day), DOY=yday(Date)) %>%
  select(Year, DOY, Tmin)
# Predict the number and accumulated damage of the spring frosts using the
# critical values contained in the example dataset Tcrits_peach and extract
# the dataframe with the total results for each year
Frost_BT <- spring_frost(Tmin_Tudela, Phenology_BT, Tcrits_peach, 181)
Frost_results <- as.data.frame(Frost_BT[['Damage_frosts']])
```

---

sunburn — *Evaluation of weather conditions for sunburn in apple fruit surface*

Description

This function estimates the number of days in which apple fruit surface temperature (FST) exceeds the thresholds indicated by Rackso and Schrader (2012) for two types of sunburn damages.

Usage

```
sunburn(climdata, first_d, last_d)
```

Arguments

`climdata`	a dataframe with daily maximum and minimum temperatures. Must contain the columns Year, Month, Day, Tmax, Tmin.
`first_d`	Numeric, it is the first date, indicated as day of the year (DOY), in the assessment.
`last_d`	a vector with the last(s) dates for the assessment (as DOY). Examples could be harvest dates for several cultivars.

Details

Sunburn necrosis (SN), the most severe type of sunburn, with a dark brown or black necrotic spot on the exposed fruit surface is considered to appear when FST reaches 52ºC. Sunburn browning (SB) is the most prevalent type of sunburn on attached sun-exposed apples (acclimated to high light). The threshold temperature for SB is set in 46ºC, and corresponds to the most sensitive apple cultivars (like Cameo or Honeycrisp).

FST is estimated from daily maximum air temperature using the expression proposed by Schrader et al (2003).

Value

data frame with the number of days within the assessed period(s). Contains the columns Year, Harvest (values from last_d), SB_browning and SB_necrosis.

Author(s)

Carlos Miranda, <carlos.miranda@unavarra.es>

References

Rackso J and Schrader LE, 2012. Sunburn of apple fruit: Historical background, recent advances and future perspectives. Critical Reviews in Plant Sciences 31, 455-504.

Schrader L, Zhang J and Sun J, 2003. Environmental stresses that cause sunburn of apple. Acta Horticulturae 618, 397-405.

Examples

```
# Create one vector with start date (i.e. hand thinning) and a vector
# with harvest dates to test sunburn risk for several cultivars using.
library(magrittr)
library(dplyr)
library(lubridate)
Thinning_d <- 135
Harvest_d <- c(225,245,260)
Sunburn_risk <- sunburn(Tudela_DW,Thinning_d, Harvest_d)
```

Tcrits_peach — *Critical frost temperatures for peach flower buds*

Description

Critical frost damage temperatures for peach flower buds for the phenological stages between 'bud swelling' (B, 51 in Baggliolini and BBCH scales, respectively) and 'ovary surrounded by dying sepal crown' (I, 72). For use in combination with the example datasets Tudela_DW and Bigtop_reqs.

Usage

```
data("Tcrits_peach")
```

Format

A data frame with 7 observations on the following 2 variables.

`LT_10` a numeric vector, frost temperature causing 10% kill

`LT_90` a numeric vector, frost temperature causing 90% kill

Details

The 10% kill and 90% kill imply that 30 minutes at the indicated temperature is expected to cause 10% and 90% kill of the flower buds during the phenological stage. The dataset contains the critical temperatures for the same stages in the example dataset Bigtop_reqs.

Source

Miranda C, Santesteban LG, Royo JB. 2005. Variability in the relationship between frost temperature and injury level for some cultivated Prunus species. HortScience 40:357-361.

Tudela_DW — *Daily weather data from Tudela, Spain*

Description

Daily weather data (2000-2010) from Tudela, Spain, recorded at the Tudela-Montes de Cierzo automatic weather station by Gobierno de Navarra.

Format

A data frame with 4018 observations on the following 11 variables.

`Year` a numeric vector, the observation year

`Month` a numeric vector, the observation month

`Day` a numeric vector, the observation day

`Tmax` a numeric vector, daily maximum temperature in Celsius

`Tmin` a numeric vector, daily minimum temperature in Celsius

`RHmax` a numeric vector, daily maximum relative humidity in %

`RHmin` a numeric vector, daily minimum relative humidity in %

`Prec` a numeric vector, daily rainfall in mm

`u2med` a numeric vector, daily mean wind speed in m s-1

`u2max` a numeric vector, daily maximum wind speed in m s-1

`Rad` a numeric vector, daily solar radiation in MJ m-2 day-1

Source

http://meteo.navarra.es/estaciones/descargardatos_estacion.cfm?IDEstacion=36

wind_scab — *Estimation of the risk for wind scab on fruit skin*

Description

The function estimates the risk of wind-induced abrasion injuries (wind scab) on fruit skin during the sensitive periods of the species. This function estimates as risky the daily hours with 'moderate breeze' wind (equal or above 5.5 m s-1 in the Beaufort scale) or stronger, estimated from a dataset with daily wind speeds.

Usage

```
wind_scab(climdata, fendata)
```

Arguments

`climdata`	a dataframe with daily wind speed data. Required columns are Year, Month, Day, u2med. u2max is optional.
`fendata`	a dataframe which can contain early fruit growth and harvest dates. Start of initial growth (Start_ing) and end of initial growth (End_ing) dates are used to assess for early wind-induced abrasion risk and harvest dates (Harvest) are used for late (pre-harvest) abrasion risks. Must contain the column Year, and can contain either Start_ing and End_ing or Harvest columns, or the three of them.

Details

Hourly wind speeds from daily values are computed using the formulas proposed by (Guo et al, 2016), using mean daily values (u2med, required) and maximum ones (u2max, optional). If only mean wind values are available, the function uses a modified version of the Guo formula, so that the maximum values are obtained in daytime hours.

Sensitive periods for wind scab in plums or nectarines correspond to the early stages of fruit growth, usually the first three weeks after full bloom (Michailides et al 1992, Michailides and Morgan 1992), mainly due to persistent leaf brushing on fruit skin between the stages '8-mm fruit' and '20-mm fruit'. A second sensitive period for cherries, plums, peaches and nectarines is pre-harvest (30 days prior to that), due to persistent friction against branches. The function allows to set both periods or only one of them.

Value

data frame with the columns Year, Day_s, Day_e, WA_efg (accumulated hours with u2>5.5 m s-1 on early fruit growth stage), Day_h, WA_bh (accumulated hours with u2>5.5 m s-1 on the month before harvest).

Author(s)

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References

Guo Z, Chang C, Wang R, 2016. A novel method to downscale daily wind statistics to hourly wind data for wind erosion modelling. In: Bian F., Xie Y. (eds) Geo-Informatics in Resource Management and Sustainable Ecosystem. GRMSE 2015. Communications in Computer and Information Science, vol 569. Springer, Berlin, Heidelberg

Michailides TJ, Morgan DP, Ramirez HT and Giacolini EL, 1992. Determination of the period when prunes are prone to development of russet scab and elucidation of the mechanism by which captan controls russet scab. California dried plum board research reports 1992, 157-175.

Michailides TJ and Morgan DP, 1992. Development of wind scab and predisposition of french prune fruits to preharvest and postharvest fungal decay by wind scab and russet scab.California dried plum board research reports 1992, 149-156.

Examples

```
# Select the appropiate columns from the example Dates_BT dataset
# and estimate wind scab risk for Big Top nectarine in Tudela using
# the example weather dataset Tudela_DW
library(magrittr)
library(dplyr)
library(lubridate)
Bloom <- Dates_BT %>%
   select(Year, sbloom) %>%
   rename(Fday=sbloom) %>%
   filter(Year==2003)

Growth_BT <- Dates_BT %>% select(Year, Start_ing, End_ing, Harvest) %>%
   filter(Year==2003)
Weather <- Tudela_DW %>%
   filter (Tudela_DW$Year==2003)
WindRisk_BT <- wind_scab(Weather, Growth_BT)
```

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