

Package ‘TTR.PGM’

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Type Package

Title Thornley Transport Resistance Plant Growth Model

Version 1.0.0

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Description An implementation of the Thornley transport resistance plant growth model. The package can be used to simulate plant growth as forced by climate system variables. The package provides methods for formatting forcing variables, simulating growth dynamics and calibrating model parameters. For more information see Higgins et al. (2025) TTR.PGM: An R package for modelling the distributions and dynamics of plants using the Thornley transport resistance plant growth model. *Methods in Ecology and Evolution*. in press.

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calc_photo

calc_photo

Description

Generates estimates of photosynthetic rates using a Farquar type photosynthesis model.

Usage

```
calc_photo(leaf_temp, photo_active_rad, atmospheric_co2, ppl, pht)
```

Arguments

leaf_temp	matrix with ntimesteps rows, nsites columns, containing leaf temperature [°C]
photo_active_rad	matrix with ntimesteps rows, nsites columns, containing photosynthetically active radiation [$\text{umol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$]
atmospheric_co2	matrix with ntimesteps rows, nsites columns, containing atmospheric CO2 partial pressure [Pa]
ppl	a list of photosynthetic parameters (see p3 and p4)
pht	a string indicating "c3" or "c4" photosynthesis

Details

This function is called internally by `get_input()`.

Value

matrix with ntimesteps rows, nsites columns, containing the calculated photosynthetic rates [$\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$]

data_input_space_Terminalia_sericea
TTR space example data

Description

This is an example dataset used for running the TTR.PGM space vignette. It includes both an occurrence data set and data on environmental covariates at the occurrence locations. It is setup so as to demonstrate the use of the `get_input()` function.

Usage

```
data(data_input_space_Terminalia_sericea)
```

Format

A dataframe with environmental data used to build a TTR input list

pts.lon

pts.lat

obs

tmax.CHELSA_tasmax_01_1981.2010_V.2.1

tmax.CHELSA_tasmax_02_1981.2010_V.2.1

tmax.CHELSA_tasmax_03_1981.2010_V.2.1

tmax.CHELSA_tasmax_04_1981.2010_V.2.1

tmax.CHELSA_tasmax_05_1981.2010_V.2.1

tmax.CHELSA_tasmax_06_1981.2010_V.2.1

tmax.CHELSA_tasmax_07_1981.2010_V.2.1

tmax.CHELSA_tasmax_08_1981.2010_V.2.1

tmax.CHELSA_tasmax_09_1981.2010_V.2.1

tmax.CHELSA_tasmax_10_1981.2010_V.2.1

tmax.CHELSA_tasmax_11_1981.2010_V.2.1

tmax.CHELSA_tasmax_12_1981.2010_V.2.1

tmin.CHELSA_tasmin_01_1981.2010_V.2.1

tmin.CHELSA_tasmin_02_1981.2010_V.2.1

tmin.CHELSA_tasmin_03_1981.2010_V.2.1

tmin.CHELSA_tasmin_04_1981.2010_V.2.1

tmin.CHELSEA_tasmin_05_1981.2010_V.2.1
tmin.CHELSEA_tasmin_06_1981.2010_V.2.1
tmin.CHELSEA_tasmin_07_1981.2010_V.2.1
tmin.CHELSEA_tasmin_08_1981.2010_V.2.1
tmin.CHELSEA_tasmin_09_1981.2010_V.2.1
tmin.CHELSEA_tasmin_10_1981.2010_V.2.1
tmin.CHELSEA_tasmin_11_1981.2010_V.2.1
tmin.CHELSEA_tasmin_12_1981.2010_V.2.1
tavg.CHELSEA_tas_01_1981.2010_V.2.1
tavg.CHELSEA_tas_02_1981.2010_V.2.1
tavg.CHELSEA_tas_03_1981.2010_V.2.1
tavg.CHELSEA_tas_04_1981.2010_V.2.1
tavg.CHELSEA_tas_05_1981.2010_V.2.1
tavg.CHELSEA_tas_06_1981.2010_V.2.1
tavg.CHELSEA_tas_07_1981.2010_V.2.1
tavg.CHELSEA_tas_08_1981.2010_V.2.1
tavg.CHELSEA_tas_09_1981.2010_V.2.1
tavg.CHELSEA_tas_10_1981.2010_V.2.1
tavg.CHELSEA_tas_11_1981.2010_V.2.1
tavg.CHELSEA_tas_12_1981.2010_V.2.1
rain.CHELSEA_pr_01_1981.2010_V.2.1
rain.CHELSEA_pr_02_1981.2010_V.2.1
rain.CHELSEA_pr_03_1981.2010_V.2.1
rain.CHELSEA_pr_04_1981.2010_V.2.1
rain.CHELSEA_pr_05_1981.2010_V.2.1
rain.CHELSEA_pr_06_1981.2010_V.2.1
rain.CHELSEA_pr_07_1981.2010_V.2.1
rain.CHELSEA_pr_08_1981.2010_V.2.1
rain.CHELSEA_pr_09_1981.2010_V.2.1
rain.CHELSEA_pr_10_1981.2010_V.2.1
rain.CHELSEA_pr_11_1981.2010_V.2.1
rain.CHELSEA_pr_12_1981.2010_V.2.1
rsds.CHELSEA_rsds_1981.2010_01_V.2.1
rsds.CHELSEA_rsds_1981.2010_02_V.2.1
rsds.CHELSEA_rsds_1981.2010_03_V.2.1
rsds.CHELSEA_rsds_1981.2010_04_V.2.1
rsds.CHELSEA_rsds_1981.2010_05_V.2.1

rsds.CHELSA_rsds_1981.2010_06_V.2.1
rsds.CHELSA_rsds_1981.2010_07_V.2.1
rsds.CHELSA_rsds_1981.2010_08_V.2.1
rsds.CHELSA_rsds_1981.2010_09_V.2.1
rsds.CHELSA_rsds_1981.2010_10_V.2.1
rsds.CHELSA_rsds_1981.2010_11_V.2.1
rsds.CHELSA_rsds_1981.2010_12_V.2.1
pet.CHELSA_pet_penman_01_1981.2010_V.2.1
pet.CHELSA_pet_penman_02_1981.2010_V.2.1
pet.CHELSA_pet_penman_03_1981.2010_V.2.1
pet.CHELSA_pet_penman_04_1981.2010_V.2.1
pet.CHELSA_pet_penman_05_1981.2010_V.2.1
pet.CHELSA_pet_penman_06_1981.2010_V.2.1
pet.CHELSA_pet_penman_07_1981.2010_V.2.1
pet.CHELSA_pet_penman_08_1981.2010_V.2.1
pet.CHELSA_pet_penman_09_1981.2010_V.2.1
pet.CHELSA_pet_penman_10_1981.2010_V.2.1
pet.CHELSA_pet_penman_11_1981.2010_V.2.1
pet.CHELSA_pet_penman_12_1981.2010_V.2.1
fc
wp

Source

See technical description

data_input_time_SA_BFA_BNP
TTR time example data

Description

This is an example dataset used for running the TTR.PGM time vignette.

Usage

```
data(data_input_time_SA_BFA_BNP)
```

Format

A dataframe with environmental data used to build a TTR input list

date
tair
tsoil1
tsoil2
tsoil3
tsoil4
srad
moist1
moist2
moist3
moist4
CA
evi
q
sif
osif
msoil
tsoil

Source

See technical description

data_map

TTR space example data for plotting maps

Description

This is an example dataset used for running the TTR.PGM space vignette. It data points. It is used to demonstrate how to plot a map from a fitted TTR.PGM model.

Usage

```
data(data_map)
```

Format

A list as produced by the 'get_input()' function.

Source

This dataset was generated by running 'get_input()' on a global grid of environmental data at 2-degree resolution.

get_input	<i>Create an input data object for make_data()</i>
-----------	--

Description

This function takes the input forcing data and formats it for use by the `make_data()` function. The input forcing data are expected to have the units specified below. All of the forcing data should be in dataframe or matrix form. The following constant dimension sizes are expected:

`nspecies` : The number of species

`nsites` : The number of sites

`nsteps` : The number of timesteps

Currently only one species is supported. Depending on the model configuration different parameters need to be specified. `tcur`, `tnur`, `tgrowth` and `tloss` always need to be supplied. For the `std` variant of the process model, `rsds` has to be specified as well. For other variants photosynthesis rates can be supplied or calculated from `tcur`, `catm` and `rsds`. Soil water content needs to be supplied or it will be calculated from `wp`, `fc`, `prec` and `pet`. `nsoil` is optional. `fire` is currently not supported.

Usage

```
get_input(  
  observations,  
  tcur,  
  tnur,  
  tgrowth,  
  tloss,  
  seconds,  
  p3 = TTR.PGM::p3,  
  p4 = TTR.PGM::p4,  
  lon = NULL,  
  lat = NULL,  
  rsds = NULL,  
  catm = NULL,  
  photoc3 = NULL,  
  photoc4 = NULL,  
  swc = NULL,  
  pet = NULL,  
  rain = NULL,  
  wp = NULL,  
  fc = NULL,  
  fire = NULL,  
  nsoil = NULL  
)
```

Arguments

observations	The observation data that will be used in the statistical model, there are no checks performed, so make sure to format this in the way the user defined statistical model expects
tcur	matrix with nimesteps rows, nsites columns, containing the temperature associated with photosynthesis [$^{\circ}\text{C}$]
tnur	matrix with nimesteps rows, nsites columns, containing the temperature associated with nitrogen uptake [$^{\circ}\text{C}$]
tgrowth	matrix with nimesteps rows, nsites columns, containing the temperature associated with growth [$^{\circ}\text{C}$]
tloss	matrix with nimesteps rows, nsites columns, containing the temperature associated with biomass loss [$^{\circ}\text{C}$]
seconds	The number of seconds in a time step
p3	The parameters to be used to calculate C3 photosynthesis rates (see p3)
p4	The parameters to be used to calculate C4 photosynthesis rates (see p4)
lon	vector of length nsite containing the Longitudes of the sites
lat	vector of length nsite containing the Latitudes of the sites
rsds	matrix with nimesteps rows, nsites columns, containing short wave downward solar radiation at the surface [$\text{W}\cdot\text{m}^{-2}$]
catm	matrix with nimesteps rows, nsites columns, containing Partial pressure of CO_2 in the atmosphere [Pa]
photoc3	matrix with nimesteps rows, nsites columns, containing c3 photosynthesis rates [$\text{mumol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$]
photoc4	matrix with nimesteps rows, nsites columns, containing c4 photosynthesis rates [$\text{mumol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$]
swc	matrix with nimesteps rows, nsites columns, containing soil water content scaled so that wilting point = 0 and field capacity = 100 [%]
pet	matrix with nimesteps rows, nsites columns, containing potential evapotranspiration [$\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$]
rain	matrix with nimesteps rows, nsites columns, containing precipitation [$\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$]
wp	vector of length nsites containing wilting points [cm^3/cm^3]
fc	vector of length nsites containing field capacities [cm^3/cm^3]
fire	matrix with nimesteps rows, nsites columns, containing binary information on fire occurrence [no units]; currently not supported
nsoil	vector of length nsites containing the soil nitrogen content [kg/kg]

Value

A list containing the forcing data for the process model:

timeseries	All forcing variables which change with time
timeinvariant	All forcing variables which do not change with time
observations	Observations as specified above

get_parms	<i>get_parms: Pack parameters in an easily accessible list</i>
-----------	--

Description

This function takes a numeric vector of all process model parameters and returns a representation that is human readable and can be used by `run_ttr()`

Usage

```
get_parms(par, Data, no.structure = FALSE)
```

Arguments

par	A numeric vector of parameters as supplied by an external parameter estimation algorithm, e.g. <code>LaplacesDemon</code> or <code>DEoptim</code>
Data	data object as returned by the <code>make_data()</code> function
no.structure	If 'TRUE', only run <code>interval_parms()</code> and <code>unname()</code> the result, this is convenient when using <code>LaplacesDemon</code> .

Value

A list containing a vector of the alpha parameters and an array of dimension (nbeta, nspecies) where nbeta is the number of beta parameters and nspecies is the number of species, containing the beta parameters per species

interval_parms	<i>interval_parms: truncate parameters into bounds</i>
----------------	--

Description

This function takes a numeric vector and constrains it to specified bounds by reflecting values outside the bounds into the interval. The bounds are defined by a data object returned by `make_data()`

Usage

```
interval_parms(par, Data)
```

Arguments

par	A numeric vector of parameters as supplied by <code>LaplacesDemon</code> or <code>DEoptim</code>
Data	A data object as returned by <code>make_data()</code>

Value

A numeric vector in which each parameter is reflected into bounds.

 make_data

Create data object for use with the process model

Description

This function creates an object representing a configuration of the process model including forcing data. This object is used by `run_ttr()`.

Usage

```
make_data(
  input,
  options = standard_options,
  globals = standard_globals,
  bounds = list(alpha = NULL, beta = NULL),
  groups = c(),
  verbose = FALSE
)
```

Arguments

input	The forcing data object created by a call to <code>get_input()</code> , see specification in its help page
options	An options list for running the model, see options help page
globals	Optional parameter specifying global variables used in the simulation, see <code>standard_globals</code> help page
bounds	Optional parameter specifying the upper and lower bounds of the model's parameters, see <code>make_data()</code> . Bounds for additional parameters included in the statistical model need to be specified here. Bounds of the process model parameters can also be modified from their default values.
groups	Optional parameter specifying the groups of process model parameters
verbose	Print out a log detailing checks

Details

The data structure produced in this function can be handed to an external parameter estimation algorithm e.g. `LaplacesDemon` or `DEoptim` to fit the model.

The bounds of the process model's parameters need to be defined. The user can supply these to `make_data()` or accept the default values returned by a call to `make_data()`. Different model variants use different parameters and a call to `make_data()` returns the default bounds for the model variant specified in `options`.

`bounds` is a list of two lists; one for alpha (per-process) parameters and one for beta (per-species) parameters. The list `bounds` is formatted as: `bounds = list(alpha = list(alpha_parameter = (lower, upper)), beta = list(beta_parameter = c(lower, upper)))`, where 'upper' specifies the maximum value a process model parameter can take on, and 'lower' is the corresponding minimum.

The external parameter estimation algorithm should then take `Data$bounds[,1]` as lower and `Data$bounds[,2]` as the upper bounds.

In case the user does not wish to estimate some of the parameters in the external optimisation process, the upper and lower bound of a parameter should be set to the same numeric value. In this case, the parameter will not be part of the `Data$bounds` matrix passed to the external parameter estimation algorithm, and its value is set internally in the `get_parms()` function.

For any group of parameters, e.g., `CU_Ns_1` and `CU_Ns_2`, setting any one of the parameters to `c(NA, NA)` will set the whole group of parameters to a constant value that will negate the influence of this parameter group on the process model. This effectively switches off the effect of these parameters on the model's processes and removes them from `Data$bounds`. The constant values the parameters are set to can be observed by inspecting the output of `get_parms()` for a `Data` object.

The names of the parameters are written as `YY_XX_i`, where `YY` specifies the process being considered and `XX` the environmental driver and `i` the parameter number in the step or trapezoid function, e.g. `CU_swc_1` and `CU_swc_2` specify how `CU` (carbon uptake) is influenced by `swc` (soil water content) and 1 and 2 specify the lower and upper parameters of the step function.

An example for specifying all process bounds for a Model run with the standard options is given in the object `'standard_bounds'`.

Value

A ttr data object, a list with the following elements:

<code>PGF</code>	Function used by LaplacesDemon for generating initial values.
<code>options</code>	Options as specified in the <code>options</code> and <code>standard_options</code> help pages
<code>globals</code>	Globals as specified in the <code>standard_globals</code> help page
<code>n.sites</code>	Number of sites
<code>n.species</code>	Number of species
<code>n.time</code>	Number of timesteps
<code>n.parm</code>	Number of parameters to be fitted
<code>n.parm.a</code>	Number of per-process parameters
<code>n.parm.b</code>	Number of per-species parameters
<code>parm.names</code>	Names of all parameters for this model configuration
<code>parm.names.a</code>	Names of per-process parameter names
<code>parm.names.b</code>	Names of per-species parameter names
<code>mon.names</code>	Required by LaplacesDemon, always set to "LP"
<code>out</code>	Names of the response variables returned by <code>run_ttr()</code>
<code>out.dimnames</code>	Dimension names for the output returned by <code>run_ttr()</code>
<code>out.dim</code>	Dimensions for the output returned by <code>run_ttr()</code>
<code>dimnames.beta</code>	Dimension names for the ttr parameters object produced by <code>get_parms()</code>
<code>bounds</code>	Bounds for all process model parameters
<code>timeseries</code>	See <code>get_input()</code>
<code>timeinvariant</code>	See <code>get_input()</code>

y	observations from get_input() cast to a matrix
lonlat	a matrix with lon and lat columns for the nsites rows
pos.oe	Indices of observation error parameters
pos.pe	Indices of process error parameters
parm.trap.groups	Representation of parameters that form a group for the trapezoid functions
arguments	The unprocessed arguments to this function, excluding data

Examples

```
#some dummy data as input
input_data <- get_input(
  observations = c(1),
  tcur = c(1),
  tnur = c(1),
  tgrowth = c(1),
  tloss = c(1),
  seconds = c(1),
  lon = c(1),
  lat = c(1),
  rsds = c(1),
  catm = c(1),
  pet = c(1),
  rain = c(1),
  wp = c(1),
  fc = c(1)
)
data <- make_data(
  input = input_data,
  options = standard_options,
  globals = standard_globals,
  bounds = list(
    alpha = list(
      #defining a new parameter, e.g. as part of a model function
      my_parameter = c(1,2),
      #overwriting a standard bound
      scale = c(0,500)
    ),
    #no more parameters than needed for the process model in beta, for these standard values.
    beta = list()
  )
)
#all standard values
data <- make_data(input_data, standard_options)
```

Description

Creates soil water content index from input precipitation, potential evapotranspiration, field capacity and wilting point.

Usage

```
make_swc(rain, pet, fc, wp, seconds, iterations)
```

Arguments

rain	matrix with nimesteps rows, nsites columns, containing precipitation [$\text{kg}\cdot\text{m}^{(-2)}\cdot\text{s}^{(-1)}$]
pet	matrix with nimesteps rows, nsites columns, containing potential evapotranspiration [$\text{kg}\cdot\text{m}^{(-2)}\cdot\text{s}^{(-1)}$]
fc	vector of length nsites containing the field capacity [cm^3/cm^3]
wp	vector of length nsites containing the wilting point [cm^3/cm^3]
seconds	number of seconds in a time step
iterations	number of times to run through the data, default is 3

Details

This function is called internally by `get_input()`.

Value

matrix with nimesteps rows, nsites columns, containing a soil water content index scaled from 0-100

options	<i>Option list used in the <code>make_data()</code> function</i>
---------	--

Description

The options list handed to `make_data()`. It specifies the process model options. An example is provided by `standard_options`.

Arguments

optim	String specifying the data calculated by the user defined Model function, e.g. one of <code>c("DEoptim", "LaplacesDemon")</code> .
ve	String specifying the version of the process model. Must be one of <code>c("std", "fqr", "red", "oak")</code> .
steps	Integer numeric vector specifying the timesteps to output. The process model will run <code>max(steps)</code> iterations and the output will contain <code>length(steps)</code> output times.

<code>initial_mass_par</code>	Boolean specifying if the initial biomass used in the process model should be estimated as a parameter.
<code>initial_mass</code>	The initial biomass to use for the process model, when <code>initial_mass_par</code> is set to FALSE.
<code>species</code>	A vector of names of species.
<code>photo</code>	A vector specifying the photosynthesis system used by the species. Must be either <code>c("c3", "c4")</code> for each species.
<code>swc_online</code>	Boolean specifying if soil water content should be calculated online as part of the process model (TRUE) or if it is given as a forcing parameter. Currently not supported.
<code>lc</code>	Boolean turning light competition simulation in the process model on/off. Currently not supported.
<code>fire</code>	Boolean turning fire in the process model on/off. Currently not supported.
<code>pe</code>	Boolean turning process error simulation on/off.
<code>pe_scale</code>	The process error scaling factor.

Details

Options to be used in the `make_data()` function

<code>p3</code>	<i>The default c3 photosynthesis parameters</i>
-----------------	---

Description

The default parameters used by `get_input()` to calculate C3 photosynthesis rates.

Usage

`p3`

Format

An object of class `list` of length 32.

p4 *The default c4 photosynthesis parameters*

Description

The default parameters used by `get_input()` to calculate C4 photosynthesis rates.

Usage

p4

Format

An object of class `list` of length 43.

predict_ttr *Make a prediction from a fitted model*

Description

Make a prediction from a fitted TTR.PGM model.

Usage

```
predict_ttr(parms, Model, Data, new.input = NULL, options = NULL, optim = NULL)
```

Arguments

parms	A vector of parameters compatible with the data object 'Data' and the user defined Model function
Model	A user defined Model function that accepts 'parms' and 'Data' as input
Data	A Data object as produced by <code>make_data()</code>
new.input	If the prediction should use different forcing data from 'Data', this can be an input object as returned by <code>get_input()</code>
options	If the prediction should use different options from 'Data', this can be supplied as an options list as required by <code>make_data()</code>
optim	If the user defined Model function tests for 'optim' in options, this can be used to set it. Defaults to the string "no"

Details

`predict_ttr()` returns the data object specified when the option 'Data\$options\$optim' in the user defined Model is set to "no". See the vignette for an example.

Value

The prediction as specified in the user defined Model function

run_ttr	<i>run_ttr: Simulate the TTR model</i>
---------	--

Description

run_ttr: Simulate the TTR model

Usage

```
run_ttr(parm, data)
```

Arguments

parm	The parameters as returned by the get_parms() function
data	The model object as defined in the make_data() function, see its help page for details

Value

A four-dimensional matrix-object with the dimensions (output_var,species,time,site) where:

output_var	refers to the array of output values produced by the process model. For identifiers, check Data\$out as produced by make_data()
species	is the nth species
time	is the nth output time given in model\$options\$steps
site	is the nth site

standard_bounds	<i>Standard values for bounds</i>
-----------------	-----------------------------------

Description

This list contains the standard bounds of parameters used in the Model. See make_data() for more information on setting bounds.

Usage

```
standard_bounds
```

Format

An object of class list of length 2.

standard_globals	<i>Standard values for global parameters</i>
------------------	--

Description

This vector contains the global parameter values for the process model, which must be supplied to the `make_data()` function. The time components are the units are per modelled time step and the length of these time steps are defined by the parameter `seconds` in `make_data()`. In the descriptions below `M` indicates dry mass of structural biomass (either shoot mass `MS` or root mass `MR`).

Usage

`standard_globals`

Format

An object of class `numeric` of length 13.

Units

mmax Loss coefficient, per timestep (kg / kg M per timestep)
gmax Growth coefficient, in (kg C kg N kg M⁻²)⁻¹ per timestep
KM Size dependency of mass-loss (kg M)
CUmax Carbon uptake rate (kg C / kg shoot M per timestep)
NUMax Nitrogen uptake rate (kg N / kg shoot M per timestep)
KA Size dependency of uptake rates (kg M)
Jc Substrate inhibition coefficient for carbon (kg C / kg M)
Jn Substrate inhibition coefficient for nitrogen (in kg N / kg M)
q Scaling coefficient for substrate transport, no units
RHOc Specific carbon transport resistance, per timestep
RHOn Specific nitrogen transport resistance, per timestep
Fc Fraction of carbon in M (kg C / kg M)
Fn Fraction of nitrogen in M (kg N / kg M)

standard_options	<i>Standard options for the model</i>
------------------	---------------------------------------

Description

This list contains the standard options used by `make_data()`. It is provided here as an example. See `options` for more information.

Usage

```
standard_options
```

Format

An object of class `list` of length 9.

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