

Package ‘dendroTools’

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Type Package

Title Linear and Nonlinear Methods for Analyzing Daily and Monthly Dendroclimatological Data

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Description Provides novel dendroclimatological methods, primarily used by the Tree-ring research community. There are two core functions. The first one is `daily_response()`, which finds the optimal sequence of days that are related to one or more tree-ring proxy records. The second one is `compare_methods()`, which effectively compares several linear and nonlinear regression algorithms.

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URL <http://github.com/jernejjevsenak/dendroTools>

BugReports <http://github.com/jernejjevsenak/dendroTools/issues>

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R topics documented:

calculate_metrics	2
compare_methods	4
critical_r	9
daily_response	10
dataset_MVA	15
dataset_MVA_individual	15
dataset_TRW	16
dataset_TRW_complete	17
data_MVA	17
data_TRW	18
data_TRW_1	18
example_dataset_1	19
example_proxies_1	19
example_proxies_individual	20
glimpse_daily_data	21
KNMI_daily_transform	21
KRE_daily_temperatures	22
LJ_daily_precipitation	32
LJ_daily_temperatures	33
LJ_monthly_precipitation	43
LJ_monthly_temperatures	44
monthly_response	45
swit272	49
swit272_daily_temperatures	49
years_to_rownames	50
Index	51

calculate_metrics	<i>calculate_metrics</i>
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Description

Calculates performance metrics for train and test data. Calculated performance metrics are correlation coefficient (r), root mean squared error (RMSE), root relative squared error (RSSE), index of agreement (d), reduction of error (RE), coefficient of efficiency (CE), detrended efficiency (DE) and bias.

Usage

```
calculate_metrics(train_predicted, test_predicted, train_observed,
  test_observed, digits = 4, formula, test)
```

Arguments

train_predicted	a vector indicating predicted data for training set
test_predicted	a vector indicating predicted data for testing set
train_observed	a vector indicating observed data for training set
test_observed	a vector indicating observed data for training set
digits	integer of number of digits to be displayed
formula	an object of class "formula" (or one that can be coerced to that class): a symbolic description of the model to be fitted. This additional argument is needed to calculate DE metrics.
test	data frame with test data.

Value

a data frame of calculated test and train metrics

References

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- Witten, I.H., Frank, E., Hall, M.A., 2011. *Data Mining: Practical Machine Learning Tools and Techniques*, 3rd ed. Morgan Kaufmann Publishers, Burlington 629 pp.

Examples

```
data(example_dataset_1)
test_data <- example_dataset_1[1:30, ]
train_data <- example_dataset_1[31:55, ]
lin_mod <- lm(MVA ~., data = train_data)
train_predicted <- predict(lin_mod, train_data)
test_predicted <- predict(lin_mod, test_data)
train_observed <- train_data[, 1]
test_observed <- test_data[, 1]
calculate_metrics(train_predicted, test_predicted, train_observed,
test_observed, test = test_data, formula = MVA ~.)

test_data <- example_dataset_1[1:20, ]
train_data <- example_dataset_1[21:55, ]
library(brnn)
lin_mod <- brnn(MVA ~., data = train_data)
train_predicted <- predict(lin_mod, train_data)
test_predicted <- predict(lin_mod, test_data)
```

```

train_observed <- train_data[, 1]
test_observed <- test_data[, 1]
calculate_metrics(train_predicted, test_predicted, train_observed,
test_observed, test = test_data, formula = MVA ~.)

```

compare_methods	<i>compare_methods</i>
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Description

Calculates performance metrics for calibration (train) and validation (test) data of different regression methods: multiple linear regression (MLR), artificial neural networks with Bayesian regularization training algorithm (BRNN), (ensemble of) model trees (MT) and random forest of regression trees (RF). With the subset argument, specific methods of interest could be specified. Calculated performance metrics are the correlation coefficient (r), the root mean squared error (RMSE), the root relative squared error (RRSE), the index of agreement (d), the reduction of error (RE), the coefficient of efficiency (CE), the detrended efficiency (DE) and mean bias. For each of the considered methods, there are also residual diagnostic plots available, separately for calibration, holdout and edge data, if applicable.

Usage

```

compare_methods(formula, dataset, k = 10, repeats = 2,
  optimize = TRUE, dataset_complete = NULL, BRNN_neurons = 1,
  MT_committees = 1, MT_neighbors = 5, MT_rules = 200,
  MT_unbiased = TRUE, MT_extrapolation = 100, MT_sample = 0,
  RF_ntree = 500, RF_maxnodes = 5, RF_mtry = 1, RF_nodesize = 1,
  seed_factor = 5, digits = 3, blocked_CV = FALSE,
  PCA_transformation = FALSE, log_preprocess = TRUE,
  components_selection = "automatic", eigenvalues_threshold = 1,
  N_components = 2, round_bias_cal = 15, round_bias_val = 4,
  n_bins = 30, edge_share = 0.1, MLR_stepwise = FALSE,
  stepwise_direction = "backward", methods = c("MLR", "BRNN", "MT",
  "RF"), tuning_metric = "RMSE", BRNN_neurons_vector = c(1, 2, 3),
  MT_committees_vector = c(1, 5, 10), MT_neighbors_vector = c(0, 5),
  MT_rules_vector = c(100, 200), MT_unbiased_vector = c(TRUE, FALSE),
  MT_extrapolation_vector = c(100), MT_sample_vector = c(0),
  RF_ntree_vector = c(100, 250, 500), RF_maxnodes_vector = c(5, 10, 20,
  25), RF_mtry_vector = c(1), RF_nodesize_vector = c(1, 5, 10),
  holdout = NULL, holdout_share = 0.1, holdout_manual = NULL,
  total_reproducibility = FALSE)

```

Arguments

formula	an object of class "formula" (or one that can be coerced to that class): a symbolic description of the model to be fitted.
dataset	a data frame with dependent and independent variables as columns and (optional) years as row names.

k	number of folds for cross-validation
repeats	number of cross-validation repeats. Should be equal or more than 1
optimize	if set to TRUE (default), the optimal values for the tuning parameters will be selected in a preliminary cross-validation procedure
dataset_complete	optional, a data frame with the full length of tree-ring parameter, which will be used to reconstruct the climate variable specified with the formula argument
BRNN_neurons	number of neurons to be used for the brnn method
MT_committees	an integer: how many committee models (e.g. boosting iterations) should be used?
MT_neighbors	how many, if any, neighbors should be used to correct the model predictions
MT_rules	an integer (or NA): define an explicit limit to the number of rules used (NA let's Cubist decide).
MT_unbiased	a logical: should unbiased rules be used?
MT_extrapolation	a number between 0 and 100: since Cubist uses linear models, predictions can be outside of the range seen the training set. This parameter controls how much rule predictions are adjusted to be consistent with the training set.
MT_sample	a number between 0 and 99.9: this is the percentage of the dataset to be randomly selected for model building (not for out-of-bag type evaluation)
RF_ntree	number of trees to grow. This should not be set to too small a number, to ensure that every input row gets predicted at least a few times
RF_maxnodes	maximum number of terminal nodes trees in the forest can have
RF_mtry	number of variables randomly sampled as candidates at each split
RF_nodsize	minimum size of terminal nodes. Setting this number larger causes smaller trees to be grown (and thus take less time).
seed_factor	an integer that will be used to change the seed options for different repeats.
digits	integer of number of digits to be displayed in the final result tables
blocked_CV	default is FALSE, if changed to TRUE, blocked cross-validation will be used to compare regression methods.
PCA_transformation	if set to TRUE, all independent variables will be transformed using PCA transformation.
log_preprocess	if set to TRUE, variables will be transformed with logarithmic transformation before used in PCA
components_selection	character string specifying how to select the Principal Components used as predictors. There are three options: "automatic", "manual" and "plot_selection". If parameter is set to automatic, all scores with eigenvalues above 1 will be selected. This threshold could be changed by changing the eigenvalues_threshold argument. If parameter is set to "manual", user should set the number of components with N_components argument. If component selection is set to "plot_selection", Scree plot will be shown and user must manually enter the number of components used as predictors.

eigenvalues_threshold	threshold for automatic selection of Principal Components
N_components	number of Principal Components used as predictors
round_bias_cal	number of digits for bias in calibration period. Effects the outlook of the final ggplot of mean bias for calibration data (element 3 of the output list)
round_bias_val	number of digits for bias in validation period. Effects the outlook of the final ggplot of mean bias for validation data (element 4 of the output list)
n_bins	number of bins used for the histograms of mean bias
edge_share	the share of the data to be considered as the edge (extreme) data. This argument could be between 0.10 and 0.50. If the argument is set to 0.10, then the 5 considered to be the edge data.
MLR_stepwise	if set to TRUE, stepwise selection of predictors will be used for the MLR method
stepwise_direction	the mode of stepwise search, can be one of "both", "backward", or "forward", with a default of "backward".
methods	a vector of strings related to methods that will be compared. A full method vector is <code>methods = c("MLR", "BRNN", "MT", "RF")</code> . To use only a subset of methods, pass a vector of methods that you would like to compare.
tuning_metric	a string that specifies what summary metric will be used to select the optimal value of tuning parameters. By default, the argument is set to "RMSE". It is also possible to use "RSquared".
BRNN_neurons_vector	a vector of possible values for BRNN_neurons argument optimization
MT_committees_vector	a vector of possible values for MT_committees argument optimization
MT_neighbors_vector	a vector of possible values for MT_neighbors argument optimization
MT_rules_vector	a vector of possible values for MT_rules argument optimization
MT_unbiased_vector	a vector of possible values for MT_unbiased argument optimization
MT_extrapolation_vector	a vector of possible values for MT_extrapolation argument optimization
MT_sample_vector	a vector of possible values for MT_sample argument optimization
RF_ntree_vector	a vector of possible values for RF_ntree argument optimization
RF_maxnodes_vector	a vector of possible values for RF_maxnodes argument optimization
RF_mtry_vector	a vector of possible values for RF_mtry argument optimization
RF_nodsize_vector	a vector of possible values for RF_nodsize argument optimization

holdout	this argument is used to define observations, which are excluded from the cross-validation and hyperparameters optimization. The holdout argument must be a character with one of the following inputs: “early”, “late” or “manual”. If "early" or "late" characters are specified, then the early or late years will be used as a holdout data. How many of the "early" or "late" years are used as a holdout is specified with the argument holdout_share. If the argument holdout is set to “manual”, then supply a vector of years (or row names) to the argument holdout_manual. Defined years will be used as a holdout. For the holdout data, the same statistical measures are calculated as for the cross-validation. The results for holdout metrics are given in the output element \$holdout_results.
holdout_share	the share of the whole dataset to be used as a holdout. Default is 0.10.
holdout_manual	a vector of years (or row names) which will be used as a holdout. calculated as for the cross-validation.
total_reproducibility	logical, default is FALSE. This argument ensures total reproducibility despite the inclusion/exclusion of different methods. By default, the optimization is done only for the methods, that are included in the methods vector. If one method is absent or added, the optimization phase is different, and this affects all the final cross-validation results. By setting the total_reproducibility = TRUE, all methods will be optimized, even though they are not included in the methods vector and the final results will be subset based on the methods vector. Setting the total_reproducibility to TRUE will result in longer optimization phase as well.

Value

a list with twelve elements:

1	\$mean_std	data frame with calculated metrics for the selected regression methods. For each regression method, the mean and standard deviation of the metrics are given.
2	\$ranks	data frame with ranks of calculated metrics: mean rank and share of rank_1 are given
3	\$edge_results	data frame with calculated performance metrics for the central-edge test. The central part of the data is used for calibration and the edge part for validation.
4	\$holdout_results	calculated metrics for the holdout data
5	\$bias_cal	ggplot object of mean bias for calibration data
6	\$bias_val	ggplot object of mean bias for validation data
7	\$transfer_functions	ggplot or plotly object with transfer functions of methods
8	\$transfer_functions_together	ggplot or plotly object with transfer functions of methods plotted together
9	\$parameter_values	a data frame with specifications of parameters used for different regression methods
10	\$PCA_output	princomp object: the result output of the PCA analysis
11	\$reconstructions	ggplot object: reconstructed dependent variable based on the dataset_complete argument
12	\$reconstructions_together	ggplot object: reconstructed dependent variable based on the dataset_complete argument
13	\$normal_QQ_cal	normal q-q plot for calibration data
14	\$normal_QQ_holdout	normal q-q plot for holdout data
15	\$normal_QQ_edge	normal q-q plot for edge data
16	\$residuals_vs_fitted_cal	residuals vs fitted values plot for calibration data
17	\$residuals_vs_fitted_holdout	residuals vs fitted values plot for holdout data
18	\$residuals_vs_fitted_edge	residuals vs fitted values plot for edge data

References

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- Perez-Rodriguez, P., Gianola, D., 2016. Brnn: Brnn (Bayesian Regularization for Feed-forward Neural Networks). R package version 0.6.
- Quinlan, J.R., 1992. Learning with Continuous Classes, *Proceedings of the 5th Australian Joint Conference on Artificial Intelligence (AI '92)*. World Scientific, Hobart, pp. 343-348.

Examples

```
## Not run:

# An example with default settings of machine learning algorithms
library(dendroTools)
data(example_dataset_1)
example_1 <- compare_methods(formula = MVA~., dataset = example_dataset_1,
edge_share = 0, holdout = "late")
example_1$mean_std
example_1$holdout_results
example_1$edge_results
example_1$ranks
example_1$bias_cal
example_1$bias_val
example_1$transfer_functions
example_1$transfer_functions_together
example_1$PCA_output
example_1$parameter_values
example_1$residuals_vs_fitted_cal
example_1$residuals_vs_fitted_edge
example_1$residuals_vs_fitted_holdout
example_1$normal_QQ_cal
example_1$normal_QQ_edge
example_1$normal_QQ_holdout

example_2 <- compare_methods(formula = MVA ~ T_APR,
dataset = example_dataset_1, k = 5, repeats = 10, BRNN_neurons = 1,
```



```

RF_ntree = 100, RF_mtry = 2, RF_maxnodes = 35, seed_factor = 5)
example_2$mean_std
example_2$rank
example_2$bias_cal
example_2$transfer_functions
example_2$transfer_functions_together
example_2$PCA_output
example_2$parameter_values

example_3 <- compare_methods(formula = MVA ~ .,
dataset = example_dataset_1, k = 2, repeats = 5,
methods = c("MLR", "BRNN", "MT"),
optimize = TRUE, MLR_stepwise = TRUE)
example_3$mean_std
example_3$rank
example_3$bias_val
example_3$transfer_functions
example_3$transfer_functions_together
example_3$parameter_values

library(dendroTools)
library(ggplot2)
data(dataset_TRW)
comparison_TRW <- compare_methods(formula = T_Jun_Jul ~ TRW, dataset = dataset_TRW,
k = 3, repeats = 10, optimize = FALSE, methods = c("MLR", "BRNN", "RF", "MT"),
seed_factor = 5, dataset_complete = dataset_TRW_complete, MLR_stepwise = TRUE,
stepwise_direction = "backward")
comparison_TRW$mean_std
comparison_TRW$bias_val
comparison_TRW$transfer_functions + xlab(expression(paste('TRW'))) +
ylab("June-July Mean Temperature [°C]")
comparison_TRW$reconstructions
comparison_TRW$reconstructions_together
comparison_TRW$edge_results

## End(Not run)

```

critical_r

critical_r

Description

Calculates critical value of Pearson correlation coefficient for a selected alpha.

Usage

```
critical_r(n, alpha = 0.05)
```

Arguments

n	number of observations
alpha	significance level

Value

calculated critical value of Pearson correlation coefficient

Examples

```
threshold_1 <- critical_r(n = 55, alpha = 0.01)
threshold_2 <- critical_r(n = 55, alpha = 0.05)
```

daily_response	<i>daily_response</i>
----------------	-----------------------

Description

Function calculates all possible values of a selected statistical metric between one or more response variables and daily sequences of environmental data. Calculations are based on moving window which is defined with two arguments: window width and a location in a matrix of daily sequences of environmental data. Window width could be fixed (use `fixed_width`) or variable width (use `lower_limit` and `upper_limit` arguments). In this case, all window widths between lower and upper limit will be used. All calculated metrics are stored in a matrix. The location of stored calculated metric in the matrix is indicating a window width (row names) and a location in a matrix of daily sequences of environmental data (column names).

Usage

```
daily_response(response, env_data, method = "lm", metric = "r.squared",
  lower_limit = 30, upper_limit = 90, fixed_width = 0,
  previous_year = FALSE, neurons = 1, brnn_smooth = TRUE,
  remove_insignificant = TRUE, alpha = 0.05,
  row_names_subset = FALSE, PCA_transformation = FALSE,
  log_preprocess = TRUE, components_selection = "automatic",
  eigenvalues_threshold = 1, N_components = 2,
  aggregate_function = "mean", temporal_stability_check = "sequential",
  k = 2, k_running_window = 30, cross_validation_type = "blocked",
  subset_years = NULL, plot_specific_window = NULL, ylimits = NULL,
  seed = NULL, tidy_env_data = FALSE, reference_window = "start")
```

Arguments

response	a data frame with tree-ring proxy variables as columns and (optional) years as row names. Row.names should be matched with those from a <code>env_data</code> data frame. If not, set <code>row_names_subset = TRUE</code> .
----------	--

env_data	a data frame of daily sequences of environmental data as columns and years as row names. Each row represents a year and each column represents a day of a year. Row.names should be matched with those from a response data frame. If not, set row_names_subset = TRUE. Alternatively, env_data could be a tidy data with three columns, i.e. Year, DOY and third column representing values of mean temperatures, sum of precipitation etc. If tidy data is passed to the function, set the argument tidy_env_data to TRUE.
method	a character string specifying which method to use. Current possibilities are "cor", "lm" and "brnn".
metric	a character string specifying which metric to use. Current possibilities are "r.squared" and "adj.r.squared". If method = "cor", metric is not relevant.
lower_limit	lower limit of window width
upper_limit	upper limit of window width
fixed_width	fixed width used for calculation. If fixed_width is assigned a value, upper_limit and lower_limit will be ignored
previous_year	if set to TRUE, env_data and response variables will be rearranged in a way, that also previous year will be used for calculations of selected statistical metric.
neurons	positive integer that indicates the number of neurons used for brnn method
brnn_smooth	if set to TRUE, a smoothing algorithm is applied that removes unrealistic calculations which are a result of neural net failure.
remove_ insignificant	if set to TRUE, removes all correlations below the significant threshold level, based on a selected alpha. For "lm" and "brnn" method, squared threshold is used, which corresponds to R squared statistics.
alpha	significance level used to remove insignificant calculations.
row_names_subset	if set to TRUE, row.names are used to subset env_data and response data frames. Only years from both data frames are kept.
PCA_transformation	if set to TRUE, all variables in the response data frame will be transformed using PCA transformation.
log_preprocess	if set to TRUE, variables will be transformed with logarithmic transformation before used in PCA
components_selection	character string specifying how to select the Principal Components used as predictors. There are three options: "automatic", "manual" and "plot_selection". If argument is set to automatic, all scores with eigenvalues above 1 will be selected. This threshold could be changed by changing the eigenvalues_threshold argument. If parameter is set to "manual", user should set the number of components with N_components argument. If components selection is set to "plot_selection", Scree plot will be shown and a user must manually enter the number of components to be used as predictors.
eigenvalues_threshold	threshold for automatic selection of Principal Components
N_components	number of Principal Components used as predictors

aggregate_function	character string specifying how the daily data should be aggregated. The default is 'mean', the two other options are 'median' and 'sum'
temporal_stability_check	character string, specifying, how temporal stability between the optimal selection and response variable(s) will be analysed. Current possibilities are "sequential", "progressive" and "running_window". Sequential check will split data into k splits and calculate selected metric for each split. Progressive check will split data into k splits, calculate metric for the first split and then progressively add 1 split at a time and calculate selected metric. For running window, select the length of running window with the k_running_window argument.
k	integer, number of breaks (splits) for temporal stability and cross validation analysis.
k_running_window	the length of running window for temporal stability check. Applicable only if temporal_stability argument is set to running window.
cross_validation_type	character string, specifying, how to perform cross validation between the optimal selection and response variables. If the argument is set to "blocked", years will not be shuffled. If the argument is set to "randomized", years will be shuffled.
subset_years	a subset of years to be analyzed. Should be given in the form of subset_years = c(1980, 2005)
plot_specific_window	integer representing window width to be displayed for plot_specific
ylimits	limit of the y axes for plot_extreme and plot_specific. It should be given in the form of: ylimits = c(0,1)
seed	optional seed argument for reproducible results
tidy_env_data	if set to TRUE, env_data should be inserted as a data frame with three columns: "Year", "DOY", "Precipitation/Temperature/etc."
reference_window	character string, the reference_window argument describes, how each calculation is referred. There are three different options: 'start' (default), 'end' and 'middle'. If the reference_window argument is set to 'start', then each calculation is related to the starting day of window. If the reference_window argument is set to 'middle', each calculation is related to the middle day of window calculation. If the reference_window argument is set to 'end', then each calculation is related to the ending day of window calculation. For example, if we consider correlations with window from DOY 15 to DOY 35. If reference window is set to 'start', then this calculation will be related to the DOY 15. If the reference window is set to 'end', then this calculation will be related to the DOY 35. If the reference_window is set to 'middle', then this calculation is related to DOY 25. The optimal selection, which describes the optimal consecutive days that returns the highest calculated metric and is obtained by the \$plot_extreme output, is the same for all three reference windows.

Value

a list with 14 elements:

1	\$calculations	a matrix with calculated metrics
2	\$method	the character string of a method
3	\$metric	the character string indicating the metric used for calculations
4	\$analysed_period	the character string specifying the analysed period based on the information from row names. If
5	\$optimized_return	data frame with two columns, response variable and aggregated (averaged) daily data that return
6	\$optimized_return_all	a data frame with aggregated daily data, that returned the optimal result for the entire env_data
7	\$transfer_function	a ggplot object: scatter plot of optimized return and a transfer line of the selected method
8	\$temporal_stability	a data frame with calculations of selected metric for different temporal subsets
9	\$cross_validation	a data frame with cross validation results
10	\$plot_heatmap	ggplot2 object: a heatmap of calculated metrics
11	\$plot_extreme	ggplot2 object: line plot of a row with the highest value in a matrix of calculated metrics
12	\$plot_specific	ggplot2 object: line plot of a row with a selected window width in a matrix of calculated metrics
13	\$PCA_output	princomp object: the result output of the PCA analysis
14	\$type	the character string describing type of analysis: daily or monthly

Examples

```
## Not run:
# Load the dendroTools R package
library(dendroTools)

# Load data
data(data_MVA)
data(data_TRW)
data(data_TRW_1)
data(example_proxies_individual)
data(example_proxies_1)
data(LJ_daily_temperatures)

# 1 Example with fixed width
example_fixed_width <- daily_response(response = data_MVA, env_data = LJ_daily_temperatures,
                                     method = "cor", fixed_width = 0,
                                     row_names_subset = TRUE, remove_insignificant = TRUE,
                                     alpha = 0.05, aggregate_function = 'mean',
                                     reference_window = "end")

example_fixed_width$plot_extreme

# 2 Example for past and present
example_MVA_past <- daily_response(response = data_MVA, env_data = LJ_daily_temperatures,
                                  method = "cor", lower_limit = 21, upper_limit = 180,
                                  row_names_subset = TRUE, previous_year = TRUE,
                                  remove_insignificant = TRUE, alpha = 0.05,
                                  plot_specific_window = 60, subset_years = c(1940, 1980), aggregate_function = 'sum')

example_MVA_present <- daily_response(response = data_MVA, env_data = LJ_daily_temperatures,
                                      method = "cor", lower_limit = 21, upper_limit = 60,
                                      row_names_subset = TRUE, previous_year = TRUE,
                                      remove_insignificant = TRUE, alpha = 0.05,
```

```

plot_specific_window = 60, subset_years = c(1981, 2010),
  aggregate_function = 'sum')

example_MVA_past$plot_heatmap
example_MVA_present$plot_heatmap
example_MVA_past$plot_specific
example_MVA_present$plot_specific

# 3 Example PCA
example_PCA <- daily_response(response = example_proxies_individual,
  env_data = LJ_daily_temperatures, method = "lm",
  lower_limit = 21, upper_limit = 180,
  row_names_subset = TRUE, remove_insignificant = TRUE,
  alpha = 0.01, PCA_transformation = TRUE,
  components_selection = "manual", N_components = 2)

summary(example_PCA$PCA_output)
example_PCA$plot_heatmap

# 4 Example negative correlations
example_neg_cor <- daily_response(response = data_TRW_1, env_data = LJ_daily_temperatures,
  method = "cor", lower_limit = 21, upper_limit = 180,
  row_names_subset = TRUE, remove_insignificant = TRUE,
  alpha = 0.05)

example_neg_cor$plot_heatmap
example_neg_cor$plot_extreme
example_neg_cor$temporal_stability

# 5 Example of multiproxy analysis
summary(example_proxies_1)
cor(example_proxies_1)

example_multiproxy <- daily_response(response = example_proxies_1,
  env_data = LJ_daily_temperatures,
  method = "lm", metric = "adj.r.squared",
  lower_limit = 21, upper_limit = 180,
  row_names_subset = TRUE, previous_year = FALSE,
  remove_insignificant = TRUE, alpha = 0.05)

example_multiproxy$plot_heatmap

# 6 Example to test the temporal stability
example_MVA_ts <- daily_response(response = data_MVA, env_data = LJ_daily_temperatures,
  method = "brnn", lower_limit = 100, metric = "adj.r.squared", upper_limit = 180,
  row_names_subset = TRUE, remove_insignificant = TRUE, alpha = 0.05,
  temporal_stability_check = "running_window", k_running_window = 10)

example_MVA_ts$temporal_stability

## End(Not run)

```

dataset_MVA	<i>MVA and mean April temperature</i>
-------------	---------------------------------------

Description

A dataset with a mean vessel area (MVA) chronology of *Quercus robur* from a lowland oak forest in Eastern Slovenia and a mean April temperature. This dataset includes years for the period 2012-1934. For a detailed description about the MVA chronology development, sampling site and the calculations of mean monthly correlations, see Jevšenak and Levanič (2015).

Usage

dataset_MVA

Format

A data frame with 79 rows and 2 variables:

MVA Mean vessel area measurements from 2012 - 1934

T_Apr Mean April temperature for the meteorological station Maribor from 2012 - 1934

Source

Jevšenak J., Levanič T. 2015. Dendrochronological and wood-anatomical features of differently vital pedunculate oak (*Quercus robur* L.) stands and their response to climate. *Topola*, 195/196: 85-96

dataset_MVA_individual

Example of dataset with individual chronologies of MVA and mean April temperature

Description

A dataset of individual tree-ring chronologies from a lowland forest in Slovenia. The first row represents a value of a year in 2015.

Usage

dataset_MVA_individual

Format

A data frame with 56 rows and 54 columns :

T_Apr mean April temperature for Ljubljana

MVA_1 Mean vessel area chronology for tree 1

MVA_2 Mean vessel area chronology for tree 2 [mm²]

MVA_3 Mean vessel area chronology for tree 3 [mm²]

MVA_4 Mean vessel area chronology for tree 4 [mm²]

MVA_5 Mean vessel area chronology for tree 5 [mm²]

MVA_6 Mean vessel area chronology for tree 6 [mm²]

MVA_7 Mean vessel area chronology for tree 7 [mm²]

MVA_8 Mean vessel area chronology for tree 8 [mm²]

MVA_9 Mean vessel area chronology for tree 9 [mm²]

MVA_10 Mean vessel area chronology for tree 10 [mm²]

Source

prof. dr. Tom Levanič, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

dataset_TRW

TRW and mean June - July temperature from Albania

Description

A dataset with a tree-ring width (TRW) chronology of *Pinus nigra* from Albania and mean June-July temperature. This TRW chronology has a span of 59 years (period 2009 - 1951) and was already used to reconstruct summer temperatures by Levanič et al. (2015). In this paper, all the details about sample replication, site description and correlation statistics are described.

Usage

dataset_TRW

Format

A data frame with 59 rows and 2 variables:

TRW Standardised tree-ring width chronology of *Pinus nigra* from Albania

T_Jun_Jul Mean June - July temperature for Albania downloaded from KNMI Climate Explorer

Source

Levanič, T., Poljanšek, S., Toromani, E., 2015. Early summer temperatures reconstructed from black pine (*Pinus nigra* Arnold) tree-ring widths from Albania. *The Holocene* 25, 469-481.

dataset_TRW_complete *The complete dataset of standardized tree-ring chronology from Albania*

Description

A dataset with a tree-ring width (TRW) chronology of *Pinus nigra* from Albania. This TRW chronology has a span of 551 years (period 2009 - 1459) and was already used to reconstruct summer temperatures by Levanič et al. (2015). In this paper, all the details about sample replication, site description and correlation statistics are described.

Usage

dataset_TRW_complete

Format

A data frame with 551 rows and 1 variable:

TRW Standardised tree-ring width chronology of *Pinus nigra* from Albania

Source

Levanič, T., Poljanšek, S., Toromani, E., 2015. Early summer temperatures reconstructed from black pine (*Pinus nigra* Arnold) tree-ring widths from Albania. *The Holocene* 25, 469-481.

data_MVA *Mean vessel area example proxy from 2012 - 1940*

Description

A dataset with MVA proxy records from a lowland forest Mlace in Slovenia. The first row represents a value of a year in 2012. Row names represent years.

Usage

data_MVA

Format

A data frame with 73 rows and 1 variable:

MVA Mean vessel area [mm²] indices from 2012 - 1940

Source

prof. dr. Tom Levanič, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

`data_TRW`*Tree-ring width (TRW) example proxy from 1981 - 1757*

Description

A dataset with TRW proxy records from a site in Slovenian Alps - Vrsic. The first row represents a TRW value in a year 1757. Row names represent years.

Usage`data_TRW`**Format**

A data frame with 225 rows and 1 variable:

TRW residual TRW indices from 1981 - 1757

Source

Schweingruber, F.H., 1981. Vrsic Krajnska Gora - PCAB - ITRDB YUGO001. <https://www.ncdc.noaa.gov/paleo/study/4728>

`data_TRW_1`*Tree-ring width (TRW) data from 2012 - 1961*

Description

A dataset of tree-ring widths (TRW) from a site in Krakovo forest (Slovenia). The first row represents a value of a year in 1961.

Usage`data_TRW_1`**Format**

A data frame with 52 rows and 1 variable:

TRW Standardized tree-ring width indices from 2012 - 1961

Source

prof. dr. Tom Levanic, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

example_dataset_1 *Example of dataset as required for compare_methods()*

Description

A dataset of Mean Vessel Area (MVA) tree-ring parameter from a lowland forest in Slovenia. The first row represents a value of a year in 2012.

Usage

example_dataset_1

Format

A data frame with 58 rows and 3 columns :

MVA Mean Vessel Area measurements from 2012 - 1955

T_APR Mean April temperatures from 2012 - 1955

T_aug_sep Mean August-September temperatures from preceding growing season from 2012 - 1955

Source

prof. dr. Tom Levanic, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

example_proxies_1 *Tree-ring example proxies 1 from 2015 - 1961*

Description

A dataset with three tree-ring proxy records from a site near Ljubljana (Slovenia). The first row represents a value of a year in 1961. The three proxy records are MVA (Mean vessel area [mm²]), O (stable oxygen isotope ratios) and TRW (Tree-ring widths)

Usage

example_proxies_1

Format

A data frame with 55 rows and 3 variables:

MVA Mean vessel area [mm²] indices from 2015 - 1961

O18 Scaled Stable oxygen isotope ratios from 2015 - 1961

TRW Tree-ring widths from 2015 - 1961

Source

prof. dr. Tom Levanic, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

example_proxies_individual

Example of dataset with individual chronologies of MVA.

Description

A dataset of individual tree-ring chronologies from a lowland forest in Slovenia. The first row represents a value of a year in 2015.

Usage

example_proxies_individual

Format

A data frame with 56 rows and 54 columns :

MVA_1 Mean vessel area chronology for tree 1

MVA_2 Mean vessel area chronology for tree 2

MVA_3 Mean vessel area chronology for tree 3

MVA_4 Mean vessel area chronology for tree 4

MVA_5 Mean vessel area chronology for tree 5

MVA_6 Mean vessel area chronology for tree 6

MVA_7 Mean vessel area chronology for tree 7

MVA_8 Mean vessel area chronology for tree 8

MVA_9 Mean vessel area chronology for tree 9

MVA_10 Mean vessel area chronology for tree 10

Source

prof. dr. Tom Levanic, Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia

`glimpse_daily_data` *glimpse_daily_data*

Description

Visual presentation of daily data to spot missing values.

Usage

```
glimpse_daily_data(env_data, na.color = "red", low_color = "blue",
  high_color = "green", tidy_env_data = FALSE)
```

Arguments

<code>env_data</code>	a data frame of daily sequences of environmental data as columns and years as row names. Each row represents a year and each column represents a day of a year. Alternatively, <code>env_data</code> could be a tidy data with three columns, i.e. Year, DOY and third column representing values of mean temperatures, sum of precipitation etc. If tidy data is passed to the function, set the argument <code>tidy_env_data</code> to TRUE.
<code>na.color</code>	color to use for missing values
<code>low_color</code>	colours for low end of the gradient
<code>high_color</code>	colours for high end of the gradient
<code>tidy_env_data</code>	if set to TRUE, <code>env_data</code> should be inserted as a data frame with three columns: "Year", "DOY", "Precipitation/Temperature/etc."

Examples

```
data("LJ_daily_temperatures")
glimpse_daily_data(env_data = LJ_daily_temperatures, tidy_env_data = FALSE, na.color = "white")

data("LJ_daily_precipitation")
glimpse_daily_data(env_data = LJ_daily_precipitation, tidy_env_data = TRUE, na.color = "white")
```

`KNMI_daily_transform` *KNMI_daily_transform*

Description

transforms daily data obtained from KNMI Climate explorer into data frame suitable for `daily_response()`

Usage

```
KNMI_daily_transform(input)
```

Arguments

input typical KNMI daily data format

Value

env_data suitable for daily_response()

Examples

```
data(swit272_daily_temperatures)
proper_env_data <- KNMI_daily_transform(swit272_daily_temperatures)
```

KRE_daily_temperatures

*Daily mean temperatures for Kredarica (Alps in Slovenia) from 2017
- 1955*

Description

A dataset of daily mean temperatures in Kredarica (Slovenia). The first row represents temperatures in 1955. The first column represents the first day of a year, the second column represents the second day of a year, etc. Row names represent years.

Usage

```
KRE_daily_temperatures
```

Format

A data frame with 63 rows and 366 variables:

- X1** Temperatures on the day 1 of a year
- X2** Temperatures on the day 2 of a year
- X3** Temperatures on the day 3 of a year
- X4** Temperatures on the day 4 of a year
- X5** Temperatures on the day 5 of a year
- X6** Temperatures on the day 6 of a year
- X7** Temperatures on the day 7 of a year
- X8** Temperatures on the day 8 of a year
- X9** Temperatures on the day 9 of a year
- X10** Temperatures on the day 10 of a year
- X11** Temperatures on the day 11 of a year
- X12** Temperatures on the day 12 of a year
- X13** Temperatures on the day 13 of a year

- X14** Temperatures on the day 14 of a year
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X366 Temperatures on the day 366 of a year

Source

<http://meteo.arso.gov.si/met/sl/archive/>

LJ_daily_precipitation

Daily precipitation for Ljubljana from 2017 - 1899

Description

A dataset of daily sum of precipitation in Ljubljana (Slovenia). The first row represents precipitation in 1899.

Usage

LJ_daily_precipitation

Format

A data frame with 43068 rows and 3 variables:

Year year

DOY day of year

Precipitation Sum of precipitation

Source

<http://climexp.knmi.nl/start.cgi>

LJ_daily_temperatures *Daily mean temperatures for Ljubljana from 2016 - 1930*

Description

A dataset of daily mean temperatures in Ljubljana (Slovenia). The first row represents temperatures in 1930. The first column represents the first day of a year, the second column represents the second day of a year, etc.

Usage

LJ_daily_temperatures

Format

A data frame with 87 rows and 366 variables:

X1 Temperatures on the day 1 of a year

X2 Temperatures on the day 2 of a year

X3 Temperatures on the day 3 of a year

X4 Temperatures on the day 4 of a year

X5 Temperatures on the day 5 of a year

X6 Temperatures on the day 6 of a year

X7 Temperatures on the day 7 of a year

X8 Temperatures on the day 8 of a year

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Source

<http://climexp.knmi.nl/start.cgi>

LJ_monthly_precipitation

Monthly sums of precipitation for Ljubljana from 2018 - 1900. Tidy format.

Description

A dataset of monthly sums of precipitations in Ljubljana (Slovenia). The first row represents precipitation sum for January 1900.

Usage

```
LJ_monthly_precipitation
```

Format

A data frame with 1417 rows and 3 variables:

Year year

Month Month

Precipitation Sum of precipitation

Source

<http://climexp.knmi.nl/start.cgi>

LJ_monthly_temperatures

Monthly mean air temperatures for Ljubljana from 2015 - 1900

Description

A dataset of monthly mean air temperatures in Ljubljana (Slovenia). The first row represents temperatures in 2015. The first column represents mean January temperature, the second column represents mean February temperature. etc. Row names represent year.

Usage

LJ_monthly_temperatures

Format

A data frame with 116 rows and 12 variables:

Jan Mean monthly air temperature for January from 1900 to 2015

Feb Mean monthly air temperature for February from 1900 to 2015

Mar Mean monthly air temperature for March from 1900 to 2015

Apr Mean monthly air temperature for April from 1900 to 2015

May Mean monthly air temperature for May from 1900 to 2015

Jun Mean monthly air temperature for June from 1900 to 2015

Jul Mean monthly air temperature for July from 1900 to 2015

Aug Mean monthly air temperature for August from 1900 to 2015

Sep Mean monthly air temperature for September from 1900 to 2015

Oct Mean monthly air temperature for October from 1900 to 2015

Nov Mean monthly air temperature for November from 1900 to 2015

Dec Mean monthly air temperature for December from 1900 to 2015

Source

<http://meteo.arso.gov.si/met/sl/archive/>

monthly_response	<i>monthly_response</i>
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Description

Function calculates all possible values of a selected statistical metric between one or more response variables and monthly sequences of environmental data. Calculations are based on moving window which slides through monthly environmental data. All calculated metrics are stored in a matrix. The location of stored calculated metric in the matrix is indicating a window width (row names) and a location in a matrix of monthly sequences of environmental data (column names).

Usage

```
monthly_response(response, env_data, method = "lm",
  metric = "r.squared", previous_year = FALSE, neurons = 1,
  brnn_smooth = TRUE, remove_insignificant = TRUE, alpha = 0.05,
  row_names_subset = FALSE, PCA_transformation = FALSE,
  log_preprocess = TRUE, components_selection = "automatic",
  eigenvalues_threshold = 1, N_components = 2,
  aggregate_function = "mean", temporal_stability_check = "sequential",
  k = 2, k_running_window = 30, cross_validation_type = "blocked",
  subset_years = NULL, plot_specific_window = NULL, ylimits = NULL,
  seed = NULL, tidy_env_data = FALSE)
```

Arguments

response	a data frame with tree-ring proxy variables as columns and (optional) years as row names. Row.names should be matched with those from a env_data data frame. If not, set row_names_subset = TRUE.
env_data	a data frame of monthly sequences of environmental data as columns and years as row names. Each row represents a year and each column represents a day of a year (or month). Row.names should be matched with those from a response data frame. If not, set row_names_subset = TRUE. Alternatively, env_data could be a tidy data with three columns, i.e. Year, DOY (Month) and third column representing values of mean temperatures, sum of precipitation etc. If tidy data is passed to the function, set the argument tidy_env_data to TRUE.
method	a character string specifying which method to use. Current possibilities are "cor", "lm" and "brnn".
metric	a character string specifying which metric to use. Current possibilities are "r.squared" and "adj.r.squared". If method = "cor", metric is not relevant.
previous_year	if set to TRUE, env_data and response variables will be rearranged in a way, that also previous year will be used for calculations of selected statistical metric.
neurons	positive integer that indicates the number of neurons used for brnn method
brnn_smooth	if set to TRUE, a smoothing algorithm is applied that removes unrealistic calculations which are a result of neural net failure.

remove_insignificant	if set to TRUE, removes all correlations below the significant threshold level, based on a selected alpha. For "lm" and "brnn" method, squared threshold is used, which corresponds to R squared statistics.
alpha	significance level used to remove insignificant calculations.
row_names_subset	if set to TRUE, row.names are used to subset env_data and response data frames. Only years from both data frames are kept.
PCA_transformation	if set to TRUE, all variables in the response data frame will be transformed using PCA transformation.
log_preprocess	if set to TRUE, variables will be transformed with logarithmic transformation before used in PCA
components_selection	character string specifying how to select the Principal Components used as predictors. There are three options: "automatic", "manual" and "plot_selection". If argument is set to automatic, all scores with eigenvalues above 1 will be selected. This threshold could be changed by changing the eigenvalues_threshold argument. If parameter is set to "manual", user should set the number of components with N_components argument. If components selection is set to "plot_selection", Scree plot will be shown and a user must manually enter the number of components to be used as predictors.
eigenvalues_threshold	threshold for automatic selection of Principal Components
N_components	number of Principal Components used as predictors
aggregate_function	character string specifying how the monthly data should be aggregated. The default is 'mean', the two other options are 'median' and 'sum'
temporal_stability_check	character string, specifying, how temporal stability between the optimal selection and response variable(s) will be analysed. Current possibilities are "sequential", "progressive" and "running_window". Sequential check will split data into k splits and calculate selected metric for each split. Progressive check will split data into k splits, calculate metric for the first split and then progressively add 1 split at a time and calculate selected metric. For running window, select the length of running window with the k_running_window argument.
k	integer, number of breaks (splits) for temporal stability and cross validation analysis.
k_running_window	the length of running window for temporal stability check. Applicable only if temporal_stability argument is set to running window.
cross_validation_type	character string, specifying, how to perform cross validation between the optimal selection and response variables. If the argument is set to "blocked", years will not be shuffled. If the argument is set to "randomized", years will be shuffled.

subset_years a subset of years to be analyzed. Should be given in the form of subset_years = c(1980, 2005)

plot_specific_window integer representing window width to be displayed for plot_specific

ylimits limit of the y axes for plot_extreme and plot_specific. It should be given in the form of: ylimits = c(0,1)

seed optional seed argument for reproducible results

tidy_env_data if set to TRUE, env_data should be inserted as a data frame with three columns: "Year", "Month", "Precipitation/Temperature/etc."

Value

a list with 13 elements:

- 1 \$calculations a matrix with calculated metrics
- 2 \$method the character string of a method
- 3 \$metric the character string indicating the metric used for calculations
- 4 \$analysed_period the character string specifying the analysed period based on the information from row names. If
- 5 \$optimized_return data frame with two columns, response variable and aggregated (averaged) monthly data that re
- 6 \$optimized_return_all a data frame with aggregated monthly data, that returned the optimal result for the entire env_da
- 7 \$transfer_function a ggplot object: scatter plot of optimized return and a transfer line of the selected method
- 8 \$temporal_stability a data frame with calculations of selected metric for different temporal subsets
- 9 \$cross_validation a data frame with cross validation results
- 10 \$plot_heatmap ggplot2 object: a heatmap of calculated metrics
- 11 \$plot_extreme ggplot2 object: line or bar plot of a row with the highest value in a matrix of calculated metrics
- 12 \$plot_specific not available for monthly_response()
- 13 \$PCA_output princomp object: the result output of the PCA analysis
- 14 \$type the character string describing type of analysis: daily or monthly

Examples

```
## Not run:
# Load the dendroTools R package
library(dendroTools)

# Load data used for examples
data(data_MVA)
data(data_TRW)
data(data_TRW_1)
data(example_proxies_individual)
data(example_proxies_1)
data(LJ_monthly_temperatures)
data(LJ_monthly_precipitation)

# 1 Example with tidy precipitation data
example_tidy_data <- monthly_response(response = data_MVA, env_data = LJ_monthly_precipitation,
                                     method = "cor", row_names_subset = TRUE,
                                     remove_insignificant = TRUE, previous_year = TRUE,
                                     alpha = 0.05, aggregate_function = 'sum',
```

```

tidy_env_data = TRUE)

example_tidy_data$plot_extreme
example_tidy_data$plot_heatmap

# 2 Example with splited data for past and present
example_MVA_past <- monthly_response(response = data_MVA, env_data = LJ_monthly_temperatures,
                                     method = "cor", row_names_subset = TRUE, previous_year = TRUE,
                                     remove_insignificant = TRUE, alpha = 0.05,
                                     subset_years = c(1940, 1980), aggregate_function = 'mean')

example_MVA_present <- monthly_response(response = data_MVA, env_data = LJ_monthly_temperatures,
                                       method = "cor", row_names_subset = TRUE, alpha = 0.05,
                                       previous_year = TRUE, remove_insignificant = TRUE,
                                       subset_years = c(1981, 2010), aggregate_function = 'mean')

example_MVA_past$plot_heatmap
example_MVA_present$plot_heatmap
example_MVA_past$plot_extreme
example_MVA_present$plot_extreme

# 3 Example with principal component analysis
example_PCA <- monthly_response(response = example_proxies_individual,
                                env_data = LJ_monthly_temperatures, method = "lm",
                                row_names_subset = TRUE, remove_insignificant = TRUE,
                                alpha = 0.01, PCA_transformation = TRUE, previous_year = TRUE,
                                components_selection = "manual", N_components = 2)

summary(example_PCA$PCA_output)
example_PCA$plot_heatmap
example_PCA$plot_extreme

# 4 Example negative correlations
example_neg_cor <- monthly_response(response = data_TRW_1, alpha = 0.05,
                                    env_data = LJ_monthly_temperatures,
                                    method = "cor", row_names_subset = TRUE,
                                    remove_insignificant = TRUE)

example_neg_cor$plot_heatmap
example_neg_cor$plot_extreme
example_neg_cor$temporal_stability

# 5 Example of multiproxy analysis
summary(example_proxies_1)
cor(example_proxies_1)

example_multiproxy <- monthly_response(response = example_proxies_1,
                                       env_data = LJ_monthly_temperatures,
                                       method = "lm", metric = "adj.r.squared",
                                       row_names_subset = TRUE, previous_year = FALSE,
                                       remove_insignificant = TRUE, alpha = 0.05)

example_multiproxy$plot_heatmap

```



```
# 6 Example to test the temporal stability
example_MVA_ts <- monthly_response(response = data_MVA, env_data = LJ_monthly_temperatures,
method = "lm", metric = "adj.r.squared", row_names_subset = TRUE,
remove_insignificant = TRUE, alpha = 0.05,
temporal_stability_check = "running_window", k_running_window = 10)

example_MVA_ts$temporal_stability

## End(Not run)
```

swit272

*Standardised tree-ring width chronology swit272, Larix decidua Mill.***Description**

A TRW chronology swit272 Investigators: Bigler, C.; Claluna, A. Site_Name: Sils-Maria GR Blais dal Fo Location: Switzerland Northernmost_Latitude: 46.4333 Southernmost_Latitude: 46.4333 Easternmost_Longitude: 9.7833 Westernmost_Longitude: 9.7833 Elevation: 2100

Usage

swit272

Format

A data frame with 273 rows and 1 variable:

BLLA S Standardised TRW index

Source

<https://www.ncdc.noaa.gov/paleo/study/14108>

swit272_daily_temperatures

*Daily temperatures for swit272_daily_temperatures***Description**

Daily mean temperature (Celsius) downloaded from KNMI Climate explorer, daily fields: E-OBS 1950-now 0.25°. This is gridded data for grid point: lon = 9.875, lat = 46.375.

Usage

swit272_daily_temperatures

Format

A data frame with 43068 rows and 3 variables:

V1 character string describing date

V2 mean temperature

Source

<https://climexp.knmi.nl/>

years_to_rownames *Function returns a data frame with row names as years*

Description

Function returns a data frame with row names as years

Usage

```
years_to_rownames(data, column_year)
```

Arguments

data a data frame to be manipulated
column_year string specifying a column with years

Value

a data frame with years as row names

Examples

```
data <- data.frame(years = seq(1950, 2015), observations = rnorm(66))
new_data <- years_to_rownames(data = data, column_year = "years")

data <- data.frame(observations1 = rnorm(66), years = seq(1950, 2015),
observations2 = rnorm(66), observations3 = rnorm(66))
new_data <- years_to_rownames(data = data, column_year = "years")
```

Index

*Topic **datasets**

- data_MVA, [17](#)
 - data_TRW, [18](#)
 - data_TRW_1, [18](#)
 - dataset_MVA, [15](#)
 - dataset_MVA_individual, [15](#)
 - dataset_TRW, [16](#)
 - dataset_TRW_complete, [17](#)
 - example_dataset_1, [19](#)
 - example_proxies_1, [19](#)
 - example_proxies_individual, [20](#)
 - KRE_daily_temperatures, [22](#)
 - LJ_daily_precipitation, [32](#)
 - LJ_daily_temperatures, [33](#)
 - LJ_monthly_precipitation, [43](#)
 - LJ_monthly_temperatures, [44](#)
 - swit272, [49](#)
 - swit272_daily_temperatures, [49](#)
- calculate_metrics, [2](#)
- compare_methods, [4](#)
- critical_r, [9](#)
- daily_response, [10](#)
- data_MVA, [17](#)
 - data_TRW, [18](#)
 - data_TRW_1, [18](#)
 - dataset_MVA, [15](#)
 - dataset_MVA_individual, [15](#)
 - dataset_TRW, [16](#)
 - dataset_TRW_complete, [17](#)
- example_dataset_1, [19](#)
- example_proxies_1, [19](#)
- example_proxies_individual, [20](#)
- glimpse_daily_data, [21](#)
- KNMI_daily_transform, [21](#)
- KRE_daily_temperatures, [22](#)
- LJ_daily_precipitation, [32](#)
- LJ_daily_temperatures, [33](#)
- LJ_monthly_precipitation, [43](#)
- LJ_monthly_temperatures, [44](#)
- monthly_response, [45](#)
- swit272, [49](#)
- swit272_daily_temperatures, [49](#)
- years_to_rownames, [50](#)