Package: dendroTools (via r-universe)

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Type Package

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

Version 2.0.0

Description Provides methods for analyzing the relationships between tree-ring proxies and daily or monthly climate data. daily_response() and monthly_response() aggregate climate data over moving windows of different widths and positions, optionally extending into previous years. For each window, they calculate the correlation (Pearson, Spearman or Kendall) with a proxy, or the explained variance of linear models or Bayesian regularized neural networks with one or more proxies, and find the window with the strongest relationship. daily_response_seascorr() and monthly_response_seascorr() calculate partial correlations between a proxy and a primary climate variable, controlling for a second one, following 'seascorr' by Meko et al. (2011) <doi:10.1016/j.cageo.2011.01.013>. They also partition the variance explained in the optimal window between the two variables and can calculate the partial correlations of the second variable. The climate data in each window can be aggregated as means, sums and other statistics, or as the Standardized Precipitation-Evapotranspiration Index (SPEI) by Vicente-Serrano et al. (2010) <doi:10.1175/2009JCLI2909.1>, calculated from the climatic water balance that water_balance() derives from precipitation and temperature. The aggregated climate series can be detrended linearly or with the spline, mean, autoregressive and Friedman methods of dplR::detrend(). Windows that are not significant can be removed with a per-window test or with corrections for multiple testing. Bootstrap confidence intervals are available, and the optimal window can be checked for temporal stability and by cross-validation. compare_methods() compares multiple linear regression, neural networks, model trees and random forests for climate reconstruction. The methods are described in Jevsenak

and Levanic (2018) <doi:10.1016/j.dendro.2018.01.005>, Jevsenak et al. (2018) <doi:10.1016/j.dendro.2018.10.001> and Jevsenak (2020) <doi:10.1016/j.dendro.2020.125753>.

License GPL-3

URL https://github.com/jernejjevsenak/dendroTools

BugReports https://github.com/jernejjevsenak/dendroTools/issues

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`calculate_metrics` *calculate_metrics*

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 (RRSE), 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

Briffa, K.R., Jones, P.D., Pilcher, J.R., Hughes, M.K., 1988. Reconstructing summer temperatures in northern Fennoscandinavia back to A.D.1700 using tree ring data from Scots Pine. Arct. Alp. Res. 20, 385-394.

Fritts, H.C., 1976. Tree Rings and Climate. Academic Press, London 567 pp.

Lorenz, E.N., 1956. Empirical Orthogonal Functions and Statistical Weather Prediction. Massachusetts Institute of Technology, Department of Meteorology.

Willmott, C.J., 1981. On the validation of models. Phys. Geogr. 2, 184-194.

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 *compare_methods*

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 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_nodesize 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 se 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 methods = c("MLR", "BRNN", "MT", "RF"). 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_nodesize_vector`
: a vector of possible values for RF_nodesize 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 19 elements:

1. $mean_std - data frame with calculated metrics for the selected \ regression methods. For each regression method and each calculated metric, mean and standard deviation 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 represents the calibration data, while the edge data, i.e. extreme values, represent the test/validation data. Different regression models are calibrated using the central data and validated for the edge (extreme) data. This test is particularly important to assess the performance of models for the predictions of the extreme data. The share of the edge (extreme) data is defined with the edge_share argument
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, facet is used to split plots by methods
12. $reconstructions_together - ggplot object: reconstructed dependent variable based on the dataset_complete argument, all reconstructions are on the same plot
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
19. $reconstructions_data - raw data that is used for creating reconstruction plots

References

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Breiman, L., 1996. Bagging predictors. Machine Learning 24, 123-140.

Breiman, L., 2001. Random forests. Machine Learning 45, 5-32.

Burden, F., Winkler, D., 2008. Bayesian Regularization of Neural Networks, in: Livingstone, D.J. (ed.), Artificial Neural Networks: Methods and Applications, vol. 458. Humana Press, Totowa, NJ, pp. 23-42.

Hastie, T., Tibshirani, R., Friedman, J.H., 2009. The Elements of Statistical Learning : Data Mining, Inference, and Prediction, 2nd ed. Springer, New York xxii, 745 p. pp.

Ho, T.K., 1995. Random decision forests, Proceedings of the Third International Conference on Document Analysis and Recognition Volume 1. IEEE Computer Society, pp. 278-282.

Hornik, K., Buchta, C., Zeileis, A., 2009. Open-source machine learning: R meets Weka. Comput. Stat. 24, 225-232.

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

```
# The examples below are enclosed within donttest{} to minimize the execution
# time during R package checks. #'

# An example with default settings of machine learning algorithms
library(dendroTools)
library(ggplot2)

data(example_dataset_1)
data(dataset_TRW)

example_1 <- compare_methods(formula = MVA ~  T_APR,
dataset = example_dataset_1, k = 5, repeats = 1, BRNN_neurons = 1,
RF_ntree = 100, RF_mtry = 2, RF_maxnodes = 35, seed_factor = 5)

# example_1$mean_std
# example_1$ranks
# example_1$bias_cal
# example_1$transfer_functions
# example_1$transfer_functions_together
# example_1$PCA_output
# example_1$parameter_values

example_2 <- compare_methods(formula = MVA ~ .,
dataset = example_dataset_1, k = 2, repeats = 2,
methods = c("MLR", "BRNN", "MT"),
optimize = TRUE, MLR_stepwise = TRUE)
```

```
# example_2$mean_std
# example_2$ranks
# example_2$bias_val
# example_2$transfer_functions
# example_2$transfer_functions_together
# example_2$parameter_values

comparison_TRW <- compare_methods(formula = T_Jun_Jul ~ TRW, dataset = dataset_TRW,
k = 3, repeats = 5, 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$transfer_functions
# comparison_TRW$reconstructions
# comparison_TRW$reconstructions_together
# comparison_TRW$edge_results
# comparison_TRW$reconstructions_data
```

`critical_r` *critical_r*

Description

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

Calculates the critical value of a correlation coefficient for a selected alpha and number of observations.

Usage

```
critical_r(n, alpha = 0.05, cor_method = "pearson")

critical_r(n, alpha = 0.05, cor_method = "pearson")
```

Arguments

`n`	number of observations
`alpha`	significance level
`cor_method`	the correlation coefficient the critical value is for. One of "pearson" (the default), "spearman" or "kendall". "pearson" and "spearman" share the same formula.

Details

For Pearson correlation the critical value follows from the t distribution with n - 2 degrees of freedom. Spearman's rho uses the same transformation applied to ranks, which is the standard approximation and is accurate for the sample sizes typical of tree-ring analysis.

Kendall's tau has a different null distribution and requires a different critical value. Under the null hypothesis tau is approximately normal with variance 2(2n + 5) / 9n(n - 1), the approximation used by `cor.test` when `exact = FALSE`. Applying the Pearson formula to tau is substantially too strict: at n = 24 it gives 0.404 where the correct value is 0.286, so genuine responses are discarded.

Value

calculated critical value of Pearson correlation coefficient

the calculated critical value of the correlation coefficient

Examples

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

# Kendall's tau needs its own critical value
threshold_3 <- critical_r(n = 55, alpha = 0.05, cor_method = "kendall")
```

---

daily_response *daily_response*

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 = "cor",
  metric = "r.squared",
  cor_method = "pearson",
  lower_limit = 30,
```

```
  upper_limit = 90,
  fixed_width = 0,
  previous_year = FALSE,
  number_previous_years = NULL,
  neurons = 1,
  brnn_smooth = TRUE,
  remove_insignificant = FALSE,
  remove_insignificant_method = "alpha",
  perm_n = 999,
  cluster_threshold = "nominal",
  alpha = 0.05,
  row_names_subset = FALSE,
  aggregate_function = "mean",
  quantile_prob = 0.5,
  temporal_stability_check = "sequential",
  k = 2,
  k_running_window = 30,
  cross_validation_type = "blocked",
  subset_years = NULL,
  ylimits = NULL,
  seed = NULL,
  tidy_env_data = FALSE,
  reference_window = "start",
  boot = FALSE,
  boot_n = 1000,
  boot_ci_type = "norm",
  boot_conf_int = 0.95,
  day_interval = NULL,
  dc_method = NULL,
  dc_nyrs = NULL,
  dc_f = 0.5,
  dc_difference = FALSE,
  dc_span = "cv",
  dc_bass = 0,
  dc_scale = NULL,
  cor_na_use = "everything",
  skip_window_length = 1,
  skip_window_position = 1
)
```

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 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. For aggregate_function = 'SPEI', env_data holds the daily climatic water balance (precipitation minus potential evapotranspiration), for example from water_balance().

`method` a character string specifying which method to use. Current possibilities are "cor" (default), "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.

`cor_method` a character string indicating which correlation coefficient is to be computed. One of "pearson" (default), "kendall", or "spearman".

`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` logical. If TRUE, previous-year climate data are included in the analysis. If FALSE, no previous-year climate data are included and number_previous_years is ignored.

`number_previous_years`
integer between 1 and 5 specifying how many previous years should be included in the environmental matrix when previous_year = TRUE. For example, number_previous_years = 2 uses climate data from years t - 2, t - 1 and t for response year t. If NULL and previous_year = TRUE, one previous year is included.

`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 bellow the significant threshold level, based on a selected alpha. For "lm" and "brnn" method, squared correlation is used as a threshold

`remove_insignificant_method`
the criterion used when remove_insignificant = TRUE. One of "alpha" (per-window significance threshold; the default and the behaviour of earlier versions), "boot" (bootstrap confidence interval excludes zero; requires boot = TRUE), "fdr_BY" (false discovery rate, Benjamini-Yekutieli, valid under arbitrary dependence between windows), "fdr_BH" (Benjamini-Hochberg, valid under positive dependence and less conservative), "maxstat" (max-statistic permutation test), "sidak" (Sidak correction on the effective number of tests) or "cluster" (cluster-extent inference). The "alpha" and "boot" criteria are applied per window and therefore do not account for the number of windows screened; the remaining criteria do.

"maxstat" builds a null distribution of the largest absolute correlation obtained anywhere in the search by repeatedly shuffling the response, and retains only windows exceeding the resulting threshold. It makes no distributional assumptions but requires perm_n re-evaluations of the whole search. It is available for

method = "cor" and for method = "lm" with a single predictor, but not for method = "brnn".

"sidak" targets the same family-wise error rate as "maxstat" but estimates it analytically. The effective number of independent tests among the screened windows is obtained from the eigenvalues of their correlation matrix following Li and Ji (2005), and a Sidak correction is applied to that number rather than to the nominal count of windows. No permutations are required, so it is effectively instantaneous and is available for all methods including "brnn". Years that are missing in some of the windows, such as the first years removed by dc_method = "Ar", are left out of this estimate, rather than the windows themselves.

"sidak" is an approximation to "maxstat". Across 54 combinations of site and climate variable the two thresholds agreed to within 0.016 on average, with a maximum discrepancy of 0.038. The approximation is close to exact for strongly autocorrelated variables such as temperature, and tends to be slightly permissive for weakly autocorrelated variables such as daily precipitation, because the eigenvalue approach does not represent temporal autocorrelation. "maxstat" is therefore preferable for final results, while "sidak" is well suited to exploratory work and to method = "brnn".

"cluster" is cluster-extent inference, adapted from neuroimaging. The surface is thresholded at cluster_threshold, connected regions of supra-threshold windows are identified, and each region's mass, the sum of absolute correlations inside it, is compared against the largest mass arising in permuted surfaces. It controls the family-wise error rate over CLUSTERS rather than over windows, so it establishes that a region contains signal without identifying which windows within it carry that signal.

In tree-ring response surfaces this method has little discriminating power. A real climate signal forms one large connected region whose mass greatly exceeds anything the permuted surfaces produce, so every cluster that forms is retained and the permutation step rarely rejects. The number of windows kept is then determined by cluster_threshold rather than by the data: on a typical daily surface, raising the threshold from the nominal critical correlation to 0.45 reduced the retained area from 95 percent to 40 percent while the max-statistic threshold on the same data stayed near 0.36. It is provided for completeness and comparison; "maxstat" or "sidak" are preferable when the question is which windows carry signal. It is available only for method = "cor".

`perm_n` number of permutations used when remove_insignificant_method = "maxstat". Defaults to 999. Ignored by all other criteria.

`cluster_threshold`
the absolute correlation at which clusters are formed when remove_insignificant_method = "cluster". Either "nominal", the default, which uses the critical correlation at the chosen alpha, or a single number between 0 and 1. This is a free parameter and it largely determines how many windows are retained, so the value used is reported in $significance_filter. Ignored by all other criteria.

`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.

aggregate_function
: character string specifying how the daily data should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'min', 'max', 'quantile' and 'SPEI'. Missing days are skipped, so 'sum' adds only the days that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index (Vicente-Serrano et al. 2010) of each window. env_data must then hold the daily climatic water balance, i.e. precipitation minus potential evapotranspiration (P - PET), which can be calculated with water_balance(). The water balance is summed over the window and standardised with a log-logistic distribution fitted by unbiased probability weighted moments, the default of SPEI::spei(). Each window is standardised against all years of env_data, before they are matched with the response, so the SPEI of a year does not depend on the analysed years, and a window in a previous year is standardised as the same window in the current year. Unlike the other options, 'SPEI' does not skip missing days: a window that includes a missing day is NA in that year. DOY 366 of non-leap years is skipped. SPEI values can only be detrended by differences (dc_difference = TRUE).

quantile_prob
: numeric value between 0 and 1 specifying the quantile probability used when aggregate_function = 'quantile'. For example, quantile_prob = 0.95 calculates the 95th percentile. The default is 0.5.

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)

ylimits
: limit of the y axes for plot_extreme. 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.

boot
: logical, if TRUE, bootstrap confidence intervals are calculated for the correlation coefficients, R squared or adjusted R squared metrics and returned as $boot_lower and $boot_upper. The metrics themselves are those of the observed data, as with boot = FALSE. Versions before 2.0.0 reported the mean of the bootstrap replicates instead.

boot_n
: The number of bootstrap replicates

boot_ci_type
: A character string representing the type of bootstrap intervals: "norm" (default), "basic", "perc" or "bca". "bca" needs boot_n of at least the number of analysed years. With fewer replicates boot::boot.ci() cannot estimate bca intervals, so they are all NA, and a warning is given. Studentized intervals ("stud") are not available.

boot_conf_int
: A scalar or vector containing the confidence level(s) of the required interval(s)

day_interval
: a vector of two values defining the interval of days used for calculations. Positive values indicate days in the current year. Negative values indicate days in the previous-year block and are used only when previous_year = TRUE. If previous_year = FALSE and negative values are supplied, day_interval is ignored, a warning is issued, and the analysis is performed for the current year only using day_interval = c(1, 366). If number_previous_years > 1, the previous-year block starts with the earliest included previous year. For example, previous_year = TRUE, number_previous_years = 2 and day_interval = c(-1, 366) analyses the full sequence from DOY 1 of year t - 2 to DOY 366 of year t.

dc_method
: a character string specifying how the aggregated climate series of each moving window should be detrended before the climate-growth relationship is calculated. Detrending is applied to the aggregated series, i.e. to a vector with one value per year, and not to the raw daily data. Possible values are "none" (or NULL, the default, no detrending), "SLD" (Simple Linear Detrending, the historical dendroTools option), and the smoothers "Spline", "Mean", "Ar" and "Friedman", which follow dplR::detrend(). The smoothers are fitted in chronological order of the years given by the row names. "Ar" (prewhitening) leaves missing values at the start of each detrended window, so for method = "cor" cor_na_use is changed to "pairwise.complete.obs", with a warning, unless it already excludes missing values. The growth-specific options of dplR::detrend()

("ModNegExp", "ModHugershoff", "AgeDepSpline") are not available, because they assume strictly positive series with a biological growth trend.

`dc_nyrs` a number giving the rigidity of the smoothing spline when dc_method = "Spline". Defaults to NULL, i.e. 0.67 times the length of the series, exactly as in dplR::detrend(). Ignored by the other methods.

`dc_f` a number between 0 and 1 giving the frequency response at the wavelength given by dc_nyrs when dc_method = "Spline". Defaults to 0.5. Ignored by the other methods.

`dc_difference` logical. If FALSE (default, as in dplR::detrend()), the detrended series is calculated as a ratio between the observed series and the fitted curve. If TRUE, it is calculated as a difference. Ratio detrending is only defined for strictly positive data, such as precipitation sums, so the function stops if env_data contains negative values. Windows whose aggregated series still contains a zero, for example a completely dry precipitation window, are returned as NA. For temperature and for any other variable that can be negative, use dc_difference = TRUE. Ignored when dc_method = "SLD", which is always residual based.

`dc_span` the span used by the Friedman super smoother when dc_method = "Friedman". Either "cv" (default, cross-validation) or a number between 0 and 1. See also stats::supsmu(). Ignored by the other methods.

`dc_bass` a number between 0 and 10 controlling the smoothness of the Friedman super smoother when dc_method = "Friedman". Defaults to 0. See also stats::supsmu(). Ignored by the other methods.

`dc_scale` logical or NULL. If TRUE, the detrended series is divided by the standard deviation of its own values. The default (NULL) uses the convention of the selected method: TRUE for dc_method = "SLD", which preserves the behaviour of earlier dendroTools versions, and FALSE for the dplR methods, which are not rescaled in dplR::detrend(). Rescaling does not affect correlations, but it does affect the scale of $optimized_return and of the transfer function.

`cor_na_use` an optional character string giving a method for computing covariances in the presence of missing values for correlation coefficients. This must be (an abbreviation of) one of the strings "everything" (default), "all.obs", "complete.obs", "na.or.complete", or "pairwise.complete.obs". See also the documentation for the base cor() function.

`skip_window_length`
an integer specifying the frequency of window selection for the calculations of climate-growth relationships. The default value is 1, indicating that every window is included in the calculations. When set to a value greater than 1, the function selectively processes windows at regular intervals defined by this parameter. For instance, if skip_window_length = 2, the function processes every second window. Similarly, if skip_window_length = 3, every third window is processed, skipping two windows in between each selected one. This parameter allows for controlling the granularity of the analysis and can help in reducing computation time by focusing on a subset of the data.

`skip_window_position`
an integer specifying the frequency of window positions used in the calculations of climate-growth relationships. The default value is 1, indicating that every

window position is included in the calculations. When set to a value greater than 1, the function selectively processes window positions at regular intervals defined by this parameter. For instance, if skip_window_position = 2, the function processes every second window position. Similarly, if skip_window_position = 3, every third window position is processed, skipping two positions in between each selected one. This parameter allows for controlling the granularity of the analysis and can help in reducing computation time by focusing on a subset of the data.

Value

a list with 20 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 there are no row names, this argument is given as NA
5. $optimized_return - data frame with two columns, response variable and aggregated (averaged) daily data that return the optimal results. This data.frame could be directly used to calibrate a model for climate reconstruction
6. $optimized_return_all - a data frame with aggregated daily data, that returned the optimal result for the entire env_data (and not only subset of analysed years)
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. $type - the character string describing type of analysis: daily or monthly
13. $reference_window - character string, which reference window was used for calculations
14. $boot_lower - matrix with lower limit of confidence intervals of bootstrap calculations
15. $boot_upper - matrix with upper limit of confidence intervals of bootstrap calculations
16. $aggregated_climate - matrix with all aggregated climate series
17. $previous_year - logical indicating whether previous-year climate data were used
18. $number_previous_years - integer indicating how many previous years were used
19. $significance_filter - information about the significance filter applied when remove_insignificant = TRUE, including the method used, the criterion, and how many cells were removed and retained
20. $detrending - information about the climate detrending applied, i.e. the method and the settings that were used, or "none"

References

Vicente-Serrano, S.M., Begueria, S., Lopez-Moreno, J.I. (2010) A multiscalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index. Journal of Climate, 23, 1696-1718. doi:10.1175/2009JCLI2909.1

Examples

```
# The examples below are enclosed within donttest{} to minimize the execution
# time during R package checks. Additionally, all examples include the
# parameters `skip_window_length` and `skip_window_position`, which limit the
# number of combinations evaluated in climate-growth correlation calculations.
# To explore all possible combinations, users should set both parameters to 1.

# 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)

example_basic <- daily_response(response = data_MVA,
                          env_data = LJ_daily_temperatures,
                          row_names_subset = TRUE,
                          fixed_width = 25,
                          lower_limit = 35, upper_limit = 45,
                          remove_insignificant = FALSE,
                          aggregate_function = 'median',
                          alpha = 0.05, cor_method = "spearman",
                          previous_year = FALSE, boot = TRUE,
                          boot_n = 10,
                          skip_window_length = 50,
                          skip_window_position = 50,
                          reference_window = "end", k = 5,
                          dc_method = "SLD",
                          day_interval = c(1, 250))

# Detrending the climate series with a smoother, following dplR::detrend().
# LJ_daily_temperatures are temperatures in degrees Celsius and therefore
# cross zero, so differences must be used instead of the default ratios.
example_detrended <- daily_response(response = data_MVA,
                          env_data = LJ_daily_temperatures,
                          method = "cor", cor_method = "pearson",
                          row_names_subset = TRUE,
                          fixed_width = 25,
                          previous_year = FALSE,
                          remove_insignificant = FALSE,
                          aggregate_function = 'mean',
```

```
                            skip_window_length = 50,
                            skip_window_position = 50,
                            reference_window = "end", k = 5,
                            dc_method = "Friedman",
                            dc_difference = TRUE,
                            day_interval = c(1, 250))

# example_detrended$detrending

# 1 Example with fixed width. Lower and upper limits are ignored.
example_daily_response <- daily_response(response = data_MVA,
    env_data = LJ_daily_temperatures,
    method = "cor", fixed_width = 40, cor_method = "spearman",
    row_names_subset = TRUE, previous_year = TRUE,
    remove_insignificant = TRUE, boot = TRUE,
    alpha = 0.005, aggregate_function = 'mean',
    day_interval = c(-100, 250), skip_window_length = 100,
    reference_window = "start", skip_window_position = 100)

# summary(example_daily_response)
# plot(example_daily_response, type = 1)
# plot(example_daily_response, type = 2)

# 2 Example for past and present. Use subset_years argument.
example_MVA_early <- daily_response(response = data_MVA,
    env_data = LJ_daily_temperatures, cor_method = "kendall",
    method = "lm", lower_limit = 21, upper_limit = 91,
    row_names_subset = TRUE, previous_year = TRUE,
    remove_insignificant = TRUE, alpha = 0.05,
    subset_years = c(1940, 1980),
    fixed_width = 45,
    aggregate_function = 'sum',
    skip_window_length = 50,
    skip_window_position = 50)

example_MVA_late <- 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,
    subset_years = c(1981, 2010),
    skip_window_length = 50,
    skip_window_position = 50)

# plot(example_MVA_early, type = 1)
# plot(example_MVA_late, type = 1)
# plot(example_MVA_early, type = 2)
# plot(example_MVA_late, type = 2)

# 3 Example with negative correlations
example_neg_cor <- daily_response(response = data_TRW_1,
    env_data = LJ_daily_temperatures, previous_year = TRUE,
    method = "cor", lower_limit = 21, upper_limit = 90,
```

```
    row_names_subset = TRUE, remove_insignificant = TRUE,
    alpha = 0.05, skip_window_length = 50,
    skip_window_position = 50)

# summary(example_neg_cor)
# plot(example_neg_cor, type = 1)
# plot(example_neg_cor, type = 2)

# 4 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,
   skip_window_length = 50,
   skip_window_position = 50)

# plot(example_multiproxy, type = 1)

# 5 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,
   skip_window_length = 50, skip_window_position = 50)

# Check the results for temporal stability
# example_MVA_ts$temporal_stability

# 6 Example with nonlinear brnn estimation
example_brnn <- daily_response(response = data_MVA,
   env_data = LJ_daily_temperatures, method = "brnn", boot = FALSE,
   lower_limit = 100, metric = "adj.r.squared", upper_limit = 101,
   row_names_subset = TRUE, remove_insignificant = TRUE, boot_n = 10,
   skip_window_length = 50, skip_window_position = 50)

# summary(example_brnn)

# Example using quantiles for the aggregation
example_q95 <- daily_response(
response = data_MVA,
env_data = LJ_daily_temperatures,
method = "cor",
fixed_width = 30,
row_names_subset = TRUE,
previous_year = TRUE,
aggregate_function = "quantile",
quantile_prob = 0.95
```

```
)

# Example using two previous years plus the current year
example_two_previous_years <- daily_response(
response = data_MVA,
env_data = LJ_daily_temperatures,
method = "cor",
fixed_width = 60,
row_names_subset = TRUE,
previous_year = TRUE,
number_previous_years = 2,
day_interval = c(-1, 250),
skip_window_length = 50,
skip_window_position = 50
)

# Example with previous-previous year effects
example_basic <- daily_response(response = data_MVA,
                          env_data = LJ_daily_temperatures,
                          row_names_subset = TRUE,
                          reference_window = "end",
                          lower_limit = 35, upper_limit = 75,
                          previous_year = TRUE,
                          remove_insignificant = TRUE,
                          number_previous_years = 3)
plot_heatmap(example_basic)
plot_extreme(example_basic)
summary(example_basic)

# Example with SPEI for the black pine site Sezana. The residual
# chronology is built as in Izmir et al. (2024).
SEZ_chron <- dplR::chron(dplR::detrend(SEZ_rwl, method = "Spline",
                                       nyrs = 32, f = 0.5),
                         prewhiten = TRUE)
SEZ_res <- SEZ_chron[!is.na(SEZ_chron$res), "res", drop = FALSE]

daily_wb <- water_balance(
  prec = data_transform(SEZ_daily_psum, format = "daily"),
  tmin = data_transform(SEZ_daily_tmin, format = "daily"),
  tmax = data_transform(SEZ_daily_tmax, format = "daily"),
  tmean = data_transform(SEZ_daily_tavg, format = "daily"),
  lat = 45.71)

example_spei <- daily_response(response = SEZ_res,
                               env_data = daily_wb,
                               row_names_subset = TRUE,
                               aggregate_function = "SPEI",
                               lower_limit = 21, upper_limit = 120)
summary(example_spei)
plot(example_spei, type = 2)
```

daily_response_seascorr *daily_response_seascorr*

Description

Function calculates all possible partial correlation coefficients between tree-ring chronology and daily environmental (usually climate) data. Calculations are based on moving window which is defined with two arguments: lower_limit and upper_limit. All calculated (partial) correlation coefficients are stored in a matrix. The location of stored correlation 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_seascorr(
  response,
  env_data_primary,
  env_data_control,
  lower_limit = 30,
  upper_limit = 90,
  fixed_width = 0,
  previous_year = FALSE,
  number_previous_years = NULL,
  pcor_method = "pearson",
  remove_insignificant = TRUE,
  remove_insignificant_method = "alpha",
  perm_n = 999,
  cluster_threshold = "nominal",
  alpha = 0.05,
  row_names_subset = FALSE,
  aggregate_function_env_data_primary = "mean",
  quantile_prob_env_data_primary = 0.5,
  aggregate_function_env_data_control = "mean",
  quantile_prob_env_data_control = 0.5,
  temporal_stability_check = "sequential",
  k = 2,
  k_running_window = 30,
  subset_years = NULL,
  ylimits = NULL,
  seed = NULL,
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = FALSE,
  reference_window = "start",
  boot = FALSE,
  boot_n = 1000,
  boot_ci_type = "norm",
```

```
  boot_conf_int = 0.95,
  day_interval = NULL,
  dc_method = NULL,
  dc_nyrs = NULL,
  dc_f = 0.5,
  dc_difference = FALSE,
  dc_span = "cv",
  dc_bass = 0,
  dc_scale = NULL,
  dc_env_data_control = NULL,
  pcor_na_use = "everything",
  skip_window_length = 1,
  skip_window_position = 1,
  pcor_control = FALSE
)
```

Arguments

response	a data frame with tree-ring proxy variable and (optional) years as row names. Row.names should be matched with those from env_data_primary and env_data_control data frame. If not, set the row_names_subset argument to TRUE.
env_data_primary	primary 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 the response data frame. If not, set the argument row_names_subset to TRUE. Alternatively, env_data_primary 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_primary to TRUE.
env_data_control	a data frame of daily sequences of environmental data as columns and years as row names. This data is used as control for calculations of partial correlation coefficients. Each row represents a year and each column represents a day of a year. Row.names should be matched with those from the response data frame. If not, set the row_names_subset argument to TRUE. Alternatively, env_data_control 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_control to TRUE.
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	logical. Master switch for previous-year analyses. If FALSE, only the current year is analysed and number_previous_years is ignored. If TRUE, previous-year climate data are included.

number_previous_years
: integer between 1 and 5 specifying how many previous years should be included when previous_year = TRUE. For example, number_previous_years = 2 uses climate data from years t - 2, t - 1 and t for response year t. If previous_year = TRUE and number_previous_years is NULL, one previous year is used for backward compatibility.

pcor_method
: a character string indicating which partial correlation coefficient is to be computed. One of "pearson" (default), "kendall", or "spearman", can be abbreviated.

remove_insignificant
: if set to TRUE, removes all correlations bellow the significant threshold level, based on a selected alpha.

remove_insignificant_method
: the criterion used when remove_insignificant = TRUE. One of "alpha" (per-window significance threshold; the default), "boot" (bootstrap confidence interval excludes zero; requires boot = TRUE), "fdr_BY" (false discovery rate, Benjamini-Yekutieli, valid under arbitrary dependence between windows), "fdr_BH" (Benjamini-Hochberg, valid under positive dependence and less conservative), "maxstat" (max-statistic permutation test), "sidak" (Sidak correction on the effective number of tests) or "cluster" (cluster-extent inference). The "alpha" and "boot" criteria are applied per window and therefore do not account for the number of windows screened; the remaining criteria do. Degrees of freedom account for the control variable throughout.

  "maxstat" builds a null distribution of the largest absolute partial correlation obtained anywhere in the search by repeatedly shuffling the response, and retains only windows exceeding the resulting threshold. It makes no distributional assumptions but requires perm_n re-evaluations of the whole search.

  "sidak" targets the same family-wise error rate but estimates it analytically and requires no permutations. The effective number of independent tests among the screened primary windows is obtained from the eigenvalues of their correlation matrix following Li and Ji (2005), and a Sidak correction is applied to that number rather than to the nominal count of windows. Years that are missing in some of the windows, such as the first years removed by dc_method = "Ar", are left out of this estimate, rather than the windows themselves.

  "sidak" is an approximation to "maxstat", and a rougher one for partial correlations than for ordinary ones, because the null distribution also depends on the control series. Across 54 combinations of site and primary/control pairing the two thresholds agreed to within 0.020 on average, with a maximum discrepancy of 0.046. The approximation is close to exact when the primary variable is strongly autocorrelated (mean error -0.005 for temperature controlling for precipitation) and permissive when it is not (mean error -0.031 for precipitation controlling for temperature), because the eigenvalue approach does not represent temporal autocorrelation. "maxstat" is therefore preferable for final results, while "sidak" suits exploratory work.

  "cluster" is cluster-extent inference, adapted from neuroimaging. The surface is thresholded at cluster_threshold, connected regions of supra-threshold windows are identified, and each region's mass, the sum of absolute partial correlations inside it, is compared against the largest mass arising in permuted surfaces. It controls the family-wise error rate over CLUSTERS rather than over windows,

so it establishes that a region contains signal without identifying which windows within it carry it.

In tree-ring response surfaces this method has little discriminating power. A real climate signal forms one large connected region whose mass greatly exceeds anything the permuted surfaces produce, so every cluster that forms is usually retained and the permutation step rarely rejects. The number of windows kept is then determined by cluster_threshold rather than by the data. It is provided for completeness and comparison; "maxstat" or "sidak" are preferable when the question is which windows carry signal.

`perm_n` number of permutations used when remove_insignificant_method = "maxstat". Defaults to 999. Ignored by all other criteria.

`cluster_threshold`
the absolute partial correlation at which clusters are formed when remove_insignificant_method = "cluster". Either "nominal", the default, which uses the critical correlation at the chosen alpha, or a single number between 0 and 1. This is a free parameter and it largely determines how many windows are retained, so the value used is reported in $significance_filter. Ignored by all other criteria.

`alpha` significance level used to remove insignificant calculations.

`row_names_subset`
if set to TRUE, row.names are used to subset env_data_primary, env_data_control and response data frames. Only years from all three data frames are kept.

`aggregate_function_env_data_primary`
character string specifying how the daily data from env_data_primary should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'min', 'max', 'quantile' and 'SPEI'. Missing days are skipped, so 'sum' adds only the days that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index of each window from the daily climatic water balance (precipitation minus potential evapotranspiration, see water_balance()) in env_data_primary, as described for aggregate_function in daily_response(). A window that includes a missing day is NA in that year.

`quantile_prob_env_data_primary`
numeric value between 0 and 1 specifying the quantile probability used when aggregate_function_env_data_primary = 'quantile'. For example, 0.95 calculates the 95th percentile. The default is 0.5.

`aggregate_function_env_data_control`
character string specifying how the daily data from env_data_control should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'min', 'max', 'quantile' and 'SPEI'. Missing days are skipped, so 'sum' adds only the days that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index of each window from the daily climatic water balance (precipitation minus potential evapotranspiration, see water_balance()) in env_data_control, as described for aggregate_function in daily_response(). A window that includes a missing day is NA in that year.

`quantile_prob_env_data_control`
numeric value between 0 and 1 specifying the quantile probability used when aggregate_function_env_data_control = 'quantile'. For example, 0.95 calculates the 95th percentile. The default is 0.5.

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

k_running_window
: the length of running window for temporal stability check. Applicable only if temporal_stability argument is set to running window.

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

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

seed
: optional seed argument for reproducible results

tidy_env_data_primary
: if set to TRUE, env_data_primary should be inserted as a data frame with three columns: "Year", "DOY", "Precipitation/Temperature/etc."

tidy_env_data_control
: if set to TRUE, env_data_control 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.

boot
: logical, if TRUE, bootstrap confidence intervals are calculated for the partial correlation coefficients and returned as $boot_lower and $boot_upper. The coefficients themselves are those of the observed data, as with boot = FALSE. Versions before 2.0.0 reported the mean of the bootstrap replicates instead.

boot_n
: The number of bootstrap replicates

boot_ci_type
: A character string representing the type of bootstrap intervals: "norm" (default), "basic", "perc" or "bca". "bca" needs boot_n of at least the number of analysed years. With fewer replicates boot::boot.ci() cannot estimate bca intervals, so

they are all NA, and a warning is given. Studentized intervals ("stud") are not available.

`boot_conf_int` A scalar or vector containing the confidence level(s) of the required interval(s)

`day_interval` a vector of two values defining the interval of days used for calculations. Positive values indicate days in the current year. Negative values indicate days in the previous-year block. If previous_year = FALSE, negative values in day_interval are ignored with a warning and the analysis is performed for the current year only using day_interval = c(1, 366). If previous_year = TRUE and number_previous_years > 1, the previous-year block starts with the earliest included previous year. For example, previous_year = TRUE, number_previous_years = 2 and day_interval = c(-1, 366) analyses the full sequence from DOY 1 of year t - 2 to DOY 366 of year t.

`dc_method` a character string specifying how the aggregated climate series of each moving window should be detrended before the partial correlation is calculated. Detrending is applied to the aggregated series, i.e. to a vector with one value per year, and not to the raw daily data. By default the same detrending is applied to the windows of env_data_primary and env_data_control; see dc_env_data_control to detrend the control windows differently. Possible values are "none" (or NULL, the default, no detrending), "SLD" (Simple Linear Detrending, the historical dendroTools option), and the smoothers "Spline", "Mean", "Ar" and "Friedman", which follow dplR::detrend(). The smoothers are fitted in chronological order of the years given by the row names. "Ar" (prewhitening) leaves missing values at the start of each detrended window, so pcor_na_use is changed to "pairwise.complete.obs", with a warning, unless it already excludes missing values. The growth-specific options of dplR::detrend() ("ModNegExp", "ModHugershoff", "AgeDepSpline") are not available, because they assume strictly positive series with a biological growth trend.

`dc_nyrs` a number giving the rigidity of the smoothing spline when dc_method = "Spline". Defaults to NULL, i.e. 0.67 times the length of the series, exactly as in dplR::detrend(). Ignored by the other methods.

`dc_f` a number between 0 and 1 giving the frequency response at the wavelength given by dc_nyrs when dc_method = "Spline". Defaults to 0.5. Ignored by the other methods.

`dc_difference` logical. If FALSE (default, as in dplR::detrend()), the detrended series is calculated as a ratio between the observed series and the fitted curve. If TRUE, it is calculated as a difference. Ratio detrending is only defined for strictly positive data, such as precipitation sums, so the function stops if a data frame whose windows are detrended by ratios, env_data_primary or env_data_control, contains negative values. Windows whose aggregated series still contains a zero, for example a completely dry precipitation window, are returned as NA. For temperature and for any other variable that can be negative, use dc_difference = TRUE. Ignored when dc_method = "SLD", which is always residual based.

`dc_span` the span used by the Friedman super smoother when dc_method = "Friedman". Either "cv" (default, cross-validation) or a number between 0 and 1. See also stats::supsmu(). Ignored by the other methods.

`dc_bass` a number between 0 and 10 controlling the smoothness of the Friedman super

smoother when dc_method = "Friedman". Defaults to 0. See also stats::supsmu(). Ignored by the other methods.

`dc_scale` logical or NULL. If TRUE, the detrended series is divided by the standard deviation of its own values. The default (NULL) uses the convention of the selected method: TRUE for dc_method = "SLD", which preserves the behaviour of earlier dendroTools versions, and FALSE for the dplR methods, which are not rescaled in dplR::detrend(). Rescaling does not affect partial correlations, but it does affect the scale of $optimized_return and of the transfer function.

`dc_env_data_control`
NULL (default) or a named list of detrending settings for the windows of env_data_control. With NULL, the control windows are detrended exactly like the primary windows. A list replaces any of dc_method, dc_nyrs, dc_f, dc_difference, dc_span, dc_bass and dc_scale for the control windows only, and the settings it does not name are taken from the arguments above. For example, dc_method = "Spline", dc_difference = TRUE and dc_env_data_control = list(dc_difference = FALSE) detrend temperature (primary) by differences and precipitation (control) by ratios, and dc_env_data_control = list(dc_method = "none") leaves the control windows untouched.

`pcor_na_use` an optional character string giving a method for computing covariances in the presence of missing values for partial correlation coefficients. This must be (an abbreviation of) one of the strings "all.obs", "everything" (default), "complete.obs", "na.or.complete", or "pairwise.complete.obs". See also the documentation for the base partial.r in psych R package

`skip_window_length`
an integer specifying the frequency of window selection for the calculations of climate-growth relationships. The default value is 1, indicating that every window is included in the calculations. When set to a value greater than 1, the function selectively processes windows at regular intervals defined by this parameter. For instance, if skip_window_length = 2, the function processes every second window. Similarly, if skip_window_length = 3, every third window is processed, skipping two windows in between each selected one. This parameter allows for controlling the granularity of the analysis and can help in reducing computation time by focusing on a subset of the data.

`skip_window_position`
an integer specifying the frequency of window positions used in the calculations of climate-growth relationships. The default value is 1, indicating that every window position is included in the calculations. When set to a value greater than 1, the function selectively processes window positions at regular intervals defined by this parameter. For instance, if skip_window_position = 2, the function processes every second window position. Similarly, if skip_window_position = 3, every third window position is processed, skipping two positions in between each selected one. This parameter allows for controlling the granularity of the analysis and can help in reducing computation time by focusing on a subset of the data.

`pcor_control` logical. If TRUE, the partial correlations of the response with the control variable, controlling for the primary variable, are also calculated for every window. They are what the function returns when env_data_primary and env_data_control,

and their settings, are swapped. They are filtered with the same significance method and settings as the primary partial correlations, with permutation methods against the same permutations, and returned as $calculations_control. plot(x, type = 3) shows them as a heatmap, and summary() also reports the strongest of them, its window, and the value in the optimal window of the primary variable. The primary results do not change. Default is FALSE.

Value

a list with elements including:

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 there are no row names, this argument is given as NA
5. $optimized_return - data frame with two columns, response variable and aggregated (averaged) daily data that return the optimal results. This data.frame could be directly used to calibrate a model for climate reconstruction
6. $optimized_return_all - a data frame with aggregated daily data, that returned the optimal result for the entire env_data_primary (and not only subset of analysed years)
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 - not available for partial correlations
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. $type - the character string describing type of analysis: daily or monthly
13. $reference_window - character string, which reference window was used for calculations
14. $aggregated_climate_primary - matrix with all aggregated climate series of primary data
15. $aggregated_climate_control - matrix with all aggregated climate series of control data
16. $previous_year - logical indicating whether previous-year climate data were used
17. $number_previous_years - integer indicating how many previous years were used
18. $boot_lower - matrix with lower limit of bootstrap confidence intervals
19. $boot_upper - matrix with upper limit of bootstrap confidence intervals
20. $significance_filter - information about the significance filter applied when remove_insignificant = TRUE, including the method used, the criterion, and how many cells were removed and retained
21. $detrending - information about the climate detrending applied, a list with the elements primary and control, each giving the method and the settings used for those windows, or "none"

22. $variance_partitioning - a data frame for the optimal window: the correlations of the response with the primary and the control series and between them (r_response_primary, r_response_control, r_primary_control), both partial correlations (pcor_primary, pcor_control), the variance of the response explained by both series together (r_squared) and how it splits into a part unique to the primary series (unique_primary), a part unique to the control series (unique_control) and a part they share (shared, negative when one series suppresses the other). For pcor_method = "spearman" the split refers to ranks; for "kendall" it is NA
23. with pcor_control = TRUE: $calculations_control - a matrix with the partial correlations of the response with the control variable, controlling for the primary variable; $boot_lower_control and $boot_upper_control - their bootstrap confidence intervals; $significance_filter_control - the significance filter applied to them; $plot_heatmap_control - their heatmap, also shown by plot(x, type = 3)

Examples

```
# The examples below are enclosed within donttest{} to minimize the execution
# time during R package checks. Additionally, all examples include the
# parameters `skip_window_length` and `skip_window_position`, which limit the
# number of combinations evaluated in climate-growth correlation calculations.
# To explore all possible combinations, users should set both parameters to 1.

# 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)
data(LJ_daily_precipitation)

# 1 Basic example using the partial correlation coefficient
example_basic <- daily_response_seascorr(response = data_MVA,
                          env_data_primary = LJ_daily_temperatures,
                          env_data_control = LJ_daily_precipitation,
                          row_names_subset = TRUE,
                          fixed_width = 25,
                          lower_limit = 35, upper_limit = 45,
                          remove_insignificant = FALSE,
                          aggregate_function_env_data_primary = 'mean',
                          aggregate_function_env_data_control = 'mean',
                          tidy_env_data_primary = FALSE,
                          tidy_env_data_control = TRUE,
                          alpha = 0.05, pcor_method = "spearman",
                          previous_year = FALSE, boot = TRUE,
                          boot_n = 10,
                          reference_window = "end", k = 5,
                          dc_method = "SLD",
                          day_interval = c(-100, 250),
```

```
                          skip_window_position = 50,
                          skip_window_length= 50
                          )
# summary(example_basic)
# plot(example_basic, type = 1)
# plot(example_basic, type = 2)
# example_basic$optimized_return
# example_basic$optimized_return_all
# example_basic$temporal_stability

# 2 Example with fixed temporal time window
example_fixed_width <- daily_response_seascorr(response = data_MVA,
                          env_data_primary = LJ_daily_temperatures,
                          env_data_control = LJ_daily_precipitation,
                          row_names_subset = TRUE,
                          remove_insignificant = TRUE,
                          aggregate_function_env_data_primary = 'mean',
                          aggregate_function_env_data_control = 'mean',
                          alpha = 0.05,
                          dc_method = "SLD",
                          fixed_width = 45,
                          tidy_env_data_primary = FALSE,
                          tidy_env_data_control = TRUE,
                          reference_window = "end",
                          skip_window_position = 50,
                          skip_window_length= 50)

# summary(example_fixed_width)
# plot(example_fixed_width, type = 1)
# plot(example_fixed_width, type = 2)
# example_fixed_width$optimized_return
# example_fixed_width$optimized_return_all


# 3 Example using quantiles for primary and control variables
example_quantile <- daily_response_seascorr(
  response = data_MVA,
  env_data_primary = LJ_daily_temperatures,
  env_data_control = LJ_daily_precipitation,
  row_names_subset = TRUE,
  fixed_width = 30,
  previous_year = TRUE,
  aggregate_function_env_data_primary = "quantile",
  quantile_prob_env_data_primary = 0.95,
  aggregate_function_env_data_control = "quantile",
  quantile_prob_env_data_control = 0.95,
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = TRUE,
  skip_window_position = 50
)

# 4 Example using two previous years plus the current year
example_two_previous_years <- daily_response_seascorr(
```

```
  response = data_MVA,
  env_data_primary = LJ_daily_temperatures,
  env_data_control = LJ_daily_precipitation,
  row_names_subset = TRUE,
  fixed_width = 60,
  previous_year = TRUE,
  number_previous_years = 2,
  day_interval = c(-1, 250),
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = TRUE,
  skip_window_position = 50
)

# 5 Example with climate detrending, following dplR::detrend(). The
# temperatures (primary) cross zero, so they are detrended by differences.
# dc_env_data_control detrends the precipitation (control) by ratios.
example_detrended <- daily_response_seascorr(response = data_MVA,
  env_data_primary = LJ_daily_temperatures,
  env_data_control = LJ_daily_precipitation,
  row_names_subset = TRUE,
  fixed_width = 30,
  remove_insignificant = FALSE,
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = TRUE,
  dc_method = "Spline", dc_difference = TRUE,
  dc_env_data_control = list(dc_difference = FALSE),
  skip_window_position = 10)

# example_detrended$detrending

# 6 Partial correlations with both variables: temperature controlling for
# precipitation, and precipitation controlling for temperature
example_both <- daily_response_seascorr(response = data_MVA,
  env_data_primary = LJ_daily_temperatures,
  env_data_control = LJ_daily_precipitation,
  row_names_subset = TRUE,
  fixed_width = 30,
  remove_insignificant = FALSE,
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = TRUE,
  aggregate_function_env_data_control = "sum",
  pcor_control = TRUE,
  skip_window_position = 10)

# summary(example_both)
# example_both$variance_partitioning
# plot(example_both, type = 3)
```

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

Description

A dataset with MVA proxy records from a lowland forest Mlače 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 [mm^2] indices from 2012 - 1940

Source

Jernej Jevšenak, Slovenian Forestry Institute, Večna pot 2, Ljubljana, Slovenia

---

`data_transform` *data_transform*

Description

Transforms daily data with two columns (date and variable) into data frame suitable for daily or monthly analysis with dendroTools.

Usage

```
data_transform(
  input,
  format = "daily",
  monthly_aggregate_function = "auto",
  date_format = "ymd"
)
```

Arguments

`input`	typical daily data format: Data frame with two columns, first column represents date, second column represents variable, such as mean temperature, precipitation, etc. Date should be in format Year-Month-Day (e.g. "2019-05-15")
`format`	character string indicating the desired output format. Should be "daily" or "monthly". Daily format returns a data frame with 366 columns (days), while monthly format returns data frame with 12 columns (months). Years are indicated as row names.

`monthly_aggregate_function`
: character string indicating, how to aggregate daily into monthly data. It can be "mean" or "sum". Third option is "auto" (default). In this case function will try to guess whether input is temperature or precipitation data. For temperature, it will use "mean", for precipitation "sum".

`date_format`
: Describe the format of date. It should be one of "ymd", "ydm", "myd", "mdy", "dmy", "dym".

Value

env_data suitable for daily or monthly analysis with dendroTools.

Examples

```
data(swit272_daily_temperatures)
proper_daily_data <- data_transform(swit272_daily_temperatures, format = "daily",
   date_format = "ymd")

proper_monthly_data <- data_transform(swit272_daily_temperatures, format = "monthly",
   date_format = "ymd")

data(swit272_daily_precipitation)
proper_daily_data <- data_transform(swit272_daily_precipitation, format = "daily",
   date_format = "ymd")

proper_monthly_data <- data_transform(swit272_daily_precipitation, format = "monthly",
   date_format = "ymd")
```

---

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.ncei.noaa.gov/access/paleo-search/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

Tom Levanič, Slovenian Forestry Institute, Večna pot 2, Ljubljana, Slovenia

dataset_MVA *MVA and mean April temperature*

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 [mm^2]

MVA_3 Mean vessel area chronology for tree 3 [mm^2]

MVA_4 Mean vessel area chronology for tree 4 [mm^2]

MVA_5 Mean vessel area chronology for tree 5 [mm^2]

MVA_6 Mean vessel area chronology for tree 6 [mm^2]

MVA_7 Mean vessel area chronology for tree 7 [mm^2]

MVA_8 Mean vessel area chronology for tree 8 [mm^2]

MVA_9 Mean vessel area chronology for tree 9 [mm^2]

MVA_10 Mean vessel area chronology for tree 10 [mm^2]

Source

Slovenian Forestry Institute, Večna 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.

`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

Jernej Jevšenak, Slovenian Forestry Institute, Večna 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 [mm ^2]), 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 [mm^2] indices from 2015 - 1961

O18 Scaled Stable oxygen isotope ratios from 2015 - 1961

TRW Tree-ring widths from 2015 - 1961

Source

Jernej Jevšenak, Slovenian Forestry Institute, Večna 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

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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

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. 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.
na.color	color to use for missing values
low_color	colours for low end of the gradient
high_color	colours for high end of the gradient
tidy_env_data	if set to TRUE, env_data should be inserted as a data frame with three columns: "Year", "DOY", "Precipitation/Temperature/etc."

Examples

```
library(dendroTools)
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")
```

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

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X365 Temperatures on the day 365 of a year

X366 Temperatures on the day 366 of a year

Source

https://meteo.arso.gov.si/met/sl/archive/

LJ_daily_precipitation

Daily precipitation for Ljubljana from 2017 - 1900

Description

A dataset of daily sum of precipitation [mm] in Ljubljana (Slovenia). The first row represents precipitation in 1900 on DOY 1.

Usage

```
LJ_daily_precipitation
```

Format

A data frame with 43067 rows and 3 variables:

Year year

DOY day of year

Precipitation Sum of precipitation in mm

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

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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

https://meteo.arso.gov.si/met/sl/archive/

monthly_response *monthly_response*

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 = "cor",
  metric = "r.squared",
  cor_method = "pearson",
  previous_year = FALSE,
  number_previous_years = NULL,
  neurons = 1,
  lower_limit = 1,
  upper_limit = 12,
  fixed_width = 0,
  brnn_smooth = TRUE,
  remove_insignificant = TRUE,
  remove_insignificant_method = "alpha",
  perm_n = 999,
  cluster_threshold = "nominal",
  alpha = 0.05,
  row_names_subset = FALSE,
  reference_window = "start",
  aggregate_function = "mean",
  quantile_prob = 0.5,
  temporal_stability_check = "sequential",
  k = 2,
  k_running_window = 30,
  cross_validation_type = "blocked",
  subset_years = NULL,
  ylimits = NULL,
  seed = NULL,
  tidy_env_data = FALSE,
  boot = FALSE,
  boot_n = 1000,
  boot_ci_type = "norm",
  boot_conf_int = 0.95,
```

```
  month_interval = NULL,
  dc_method = NULL,
  dc_nyrs = NULL,
  dc_f = 0.5,
  dc_difference = FALSE,
  dc_span = "cv",
  dc_bass = 0,
  dc_scale = NULL,
  cor_na_use = "everything"
)
```

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. For aggregate_function = 'SPEI', env_data holds the monthly climatic water balance (precipitation minus potential evapotranspiration), for example from water_balance().
method	a character string specifying which method to use. Current possibilities are "cor" (default), "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.
cor_method	a character string indicating which correlation coefficient is to be computed. One of "pearson" (default), "kendall", or "spearman".
previous_year	logical. If TRUE, previous-year climate data are included in the analysis. If FALSE, no previous-year climate data are included and number_previous_years is ignored.
number_previous_years	integer between 1 and 5 specifying how many previous years should be included in the environmental matrix when previous_year = TRUE. For example, number_previous_years = 2 uses monthly climate data from years t - 2, t - 1 and t for response year t. If NULL and previous_year = TRUE, one previous year is included.
neurons	positive integer that indicates the number of neurons used for brnn method
lower_limit	lower limit of window width (i.e. number of consecutive months to be used for calculations)
upper_limit	upper limit of window width (i.e. number of consecutive months to be used for calculations)

`fixed_width` fixed width used for calculations (i.e. number of consecutive months to be used for calculations)

`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 bellow the significant threshold level, based on a selected alpha. For "lm" and "brnn" method, squared threshold is used, which corresponds to R squared statistics.

`remove_insignificant_method`
the criterion used when remove_insignificant = TRUE. One of "alpha" (per-window significance threshold; the default), "boot" (bootstrap confidence interval excludes zero; requires boot = TRUE), "fdr_BY" (false discovery rate, Benjamini-Yekutieli, valid under arbitrary dependence between windows), "fdr_BH" (Benjamini-Hochberg, valid under positive dependence and less conservative), "maxstat" (max-statistic permutation test), "sidak" (Sidak correction on the effective number of tests) or "cluster" (cluster-extent inference). The "alpha" and "boot" criteria are applied per window and therefore do not account for the number of windows screened; the remaining criteria do.

"maxstat" builds a null distribution of the largest absolute correlation obtained anywhere in the search by repeatedly shuffling the response, and retains only windows exceeding the resulting threshold. It makes no distributional assumptions but requires perm_n re-evaluations of the whole search. It is available for method = "cor" and for method = "lm" with a single predictor, but not for method = "brnn".

"sidak" targets the same family-wise error rate as "maxstat" but estimates it analytically. The effective number of independent tests among the screened windows is obtained from the eigenvalues of their correlation matrix following Li and Ji (2005), and a Sidak correction is applied to that number rather than to the nominal count of windows. No permutations are required, so it is effectively instantaneous and is available for all methods including "brnn". Years that are missing in some of the windows, such as the first years removed by dc_method = "Ar", are left out of this estimate, rather than the windows themselves.

"sidak" is an approximation to "maxstat". Across 54 combinations of site and climate variable the two thresholds agreed to within 0.016 on average, with a maximum discrepancy of 0.038. The approximation is close to exact for strongly autocorrelated variables such as temperature, and tends to be slightly permissive for weakly autocorrelated variables such as daily precipitation, because the eigenvalue approach does not represent temporal autocorrelation. "maxstat" is therefore preferable for final results, while "sidak" is well suited to exploratory work and to method = "brnn".

"cluster" is cluster-extent inference, adapted from neuroimaging. The surface is thresholded at cluster_threshold, connected regions of supra-threshold windows are identified, and each region's mass, the sum of absolute correlations inside it, is compared against the largest mass arising in permuted surfaces. It controls the family-wise error rate over CLUSTERS rather than over windows, so it establishes that a region contains signal without identifying which windows within it carry that signal.

In tree-ring response surfaces this method has little discriminating power. A real climate signal forms one large connected region whose mass greatly exceeds anything the permuted surfaces produce, so every cluster that forms is retained and the permutation step rarely rejects. The number of windows kept is then determined by cluster_threshold rather than by the data. It is provided for completeness and comparison; "maxstat" or "sidak" are preferable when the question is which windows carry signal. It is available only for method = "cor".

`perm_n` number of permutations used when remove_insignificant_method = "maxstat". Defaults to 999. Ignored by all other criteria.

`cluster_threshold`
the absolute correlation at which clusters are formed when remove_insignificant_method = "cluster". Either "nominal", the default, which uses the critical correlation at the chosen alpha, or a single number between 0 and 1. This is a free parameter and it largely determines how many windows are retained, so the value used is reported in $significance_filter. Ignored by all other criteria.

`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.

`reference_window`
character string, the reference_window argument describes, how each calculation is referred. There are two different options: 'start' (default) and 'end'. If the reference_window argument is set to 'start', then each calculation is related to the starting month of window. If the reference_window argument is set to 'end', then each calculation is related to the ending day of window calculation.

`aggregate_function`
character string specifying how the monthly data should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'quantile' and 'SPEI'. Missing months are skipped, so 'sum' adds only the months that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index (Vicente-Serrano et al. 2010) of each window. env_data must then hold the monthly climatic water balance, i.e. precipitation minus potential evapotranspiration (P - PET), which can be calculated with water_balance(). The water balance is summed over the window and standardised with a log-logistic distribution fitted by unbiased probability weighted moments, the default of SPEI::spei(). Each window is standardised against all years of env_data, before they are matched with the response. A window of K months ending in month m therefore has the value of SPEI::spei(scale = K) in month m, the SPEI of a year does not depend on the analysed years, and a window in a previous year is standardised as the same window in the current year. Unlike the other options, 'SPEI' does not skip missing months: a window that includes a missing month is NA in that year. SPEI values can only be detrended by differences (dc_difference = TRUE).

`quantile_prob` numeric value between 0 and 1 specifying the quantile probability used when aggregate_function = 'quantile'. For example, quantile_prob = 0.95 calculates the 95th percentile. The default is 0.5.

`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)

`ylimits`
: limit of the y axes for plot_extreme. 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."

`boot`
: logical, if TRUE, bootstrap confidence intervals are calculated for the correlation coefficients, R squared or adjusted R squared metrics and returned as $boot_lower and $boot_upper. The metrics themselves are those of the observed data, as with boot = FALSE. Versions before 2.0.0 reported the mean of the bootstrap replicates instead.

`boot_n`
: The number of bootstrap replicates

`boot_ci_type`
: A character string representing the type of bootstrap intervals: "norm" (default), "basic", "perc" or "bca". "bca" needs boot_n of at least the number of analysed years. With fewer replicates boot::boot.ci() cannot estimate bca intervals, so they are all NA, and a warning is given. Studentized intervals ("stud") are not available.

`boot_conf_int`
: A scalar or vector containing the confidence level(s) of the required interval(s)

`month_interval`
: a vector of two values defining the interval of months used for calculations. Positive values indicate months in the current year. Negative values indicate months in the previous-year block and are only used when previous_year = TRUE. If previous_year = FALSE and negative values are supplied, month_interval is ignored and the analysis is performed for the current year only using month_interval = c(1, 12). If number_previous_years > 1, the previous-year block starts with the earliest included previous year. For example, previous_year = TRUE, number_previous_years = 2 and month_interval = c(-1, 12) analyses the full sequence from January of year t - 2 to December of year t.

dc_method — a character string specifying how the aggregated climate series of each moving window should be detrended before the climate-growth relationship is calculated. Detrending is applied to the aggregated series, i.e. to a vector with one value per year, and not to the raw monthly data. Possible values are "none" (or NULL, the default, no detrending), "SLD" (Simple Linear Detrending, the historical dendroTools option), and the smoothers "Spline", "Mean", "Ar" and "Friedman", which follow dplR::detrend(). The smoothers are fitted in chronological order of the years given by the row names. "Ar" (prewhitening) leaves missing values at the start of each detrended window, so for method = "cor" cor_na_use is changed to "pairwise.complete.obs", with a warning, unless it already excludes missing values. The growth-specific options of dplR::detrend() ("ModNegExp", "ModHugershoff", "AgeDepSpline") are not available, because they assume strictly positive series with a biological growth trend.

dc_nyrs — a number giving the rigidity of the smoothing spline when dc_method = "Spline". Defaults to NULL, i.e. 0.67 times the length of the series, exactly as in dplR::detrend(). Ignored by the other methods.

dc_f — a number between 0 and 1 giving the frequency response at the wavelength given by dc_nyrs when dc_method = "Spline". Defaults to 0.5. Ignored by the other methods.

dc_difference — logical. If FALSE (default, as in dplR::detrend()), the detrended series is calculated as a ratio between the observed series and the fitted curve. If TRUE, it is calculated as a difference. Ratio detrending is only defined for strictly positive data, such as precipitation sums, so the function stops if env_data contains negative values. Windows whose aggregated series still contains a zero, for example a completely dry month, are returned as NA. For temperature and for any other variable that can be negative, use dc_difference = TRUE. Ignored when dc_method = "SLD", which is always residual based.

dc_span — the span used by the Friedman super smoother when dc_method = "Friedman". Either "cv" (default, cross-validation) or a number between 0 and 1. See also stats::supsmu(). Ignored by the other methods.

dc_bass — a number between 0 and 10 controlling the smoothness of the Friedman super smoother when dc_method = "Friedman". Defaults to 0. See also stats::supsmu(). Ignored by the other methods.

dc_scale — logical or NULL. If TRUE, the detrended series is divided by the standard deviation of its own values. The default (NULL) uses the convention of the selected method: TRUE for dc_method = "SLD", which preserves the behaviour of earlier dendroTools versions, and FALSE for the dplR methods, which are not rescaled in dplR::detrend(). Rescaling does not affect correlations, but it does affect the scale of $optimized_return and of the transfer function.

cor_na_use — an optional character string giving a method for computing covariances in the presence of missing values for correlation coefficients. This must be (an abbreviation of) one of the strings "everything" (default), "all.obs", "complete.obs", "na.or.complete", or "pairwise.complete.obs". See also the documentation for the base cor() function.

Value

a list with 20 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 there are no row names, this argument is given as NA
5. $optimized_return - data frame with two columns, response variable and aggregated (averaged) monthly data that return the optimal results. This data.frame could be directly used to calibrate a model for climate reconstruction
6. $optimized_return_all - a data frame with aggregated monthly data, that returned the optimal result for the entire env_data (and not only subset of analysed years)
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. $type - the character string describing type of analysis: daily or monthly
13. $reference_window - character string, which reference window was used for calculations
14. $boot_lower - matrix with lower limit of confidence intervals of bootstrap calculations
15. $boot_upper - matrix with upper limit of confidence intervals of bootstrap calculations
16. $significance_filter - list describing which significance filter was applied, the criterion used, and how many matrix cells were retained or removed
17. $aggregated_climate - matrix with all aggregated climate series
18. $previous_year - logical indicating whether previous-year climate data were used
19. $number_previous_years - integer indicating how many previous years were used
20. $detrending - information about the climate detrending applied, i.e. the method and the settings that were used, or "none"

References

Vicente-Serrano, S.M., Begueria, S., Lopez-Moreno, J.I. (2010) A multiscalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index. Journal of Climate, 23, 1696-1718. doi:10.1175/2009JCLI2909.1

Examples

```
# The examples below are enclosed within donttest{} to minimize the execution
# time during R package checks.

# 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,
    lower_limit = 1, upper = 24, dc_method = "SLD",
    env_data = LJ_monthly_precipitation, fixed_width = 0,
    method = "cor", row_names_subset = TRUE,
    remove_insignificant = FALSE, previous_year = FALSE,
    reference_window = "end",
    alpha = 0.05, aggregate_function = 'sum', boot = FALSE,
    tidy_env_data = TRUE, boot_n = 100, month_interval = c(-5, 10))

# summary(example_tidy_data)
# plot(example_tidy_data, type = 1)
# plot(example_tidy_data, type = 2)

# 2 Example with split data for early and late
example_MVA_early <- 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_late <- 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')

# summary(example_MVA_late)
# plot(example_MVA_early, type = 1)
# plot(example_MVA_late, type = 1)
# plot(example_MVA_early, type = 2)
# plot(example_MVA_late, type = 2)

# 3 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, boot = FALSE)

# summary(example_neg_cor)
# plot(example_neg_cor, type = 1)
# plot(example_neg_cor, type = 2)
# example_neg_cor$temporal_stability

# 4 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)

# summary(example_multiproxy)
# plot(example_multiproxy, type = 1)

# 5 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)

# summary(example_MVA_ts)
# example_MVA_ts$temporal_stability

# 6 Example using quantiles for the aggregation
example_q95 <- monthly_response(
  response = data_MVA,
  env_data = LJ_monthly_temperatures,
  method = "cor",
  fixed_width = 3,
  row_names_subset = TRUE,
  previous_year = TRUE,
  aggregate_function = "quantile",
  quantile_prob = 0.95
)

# summary(example_q95)
# example_q95$temporal_stability

# Example using two previous years plus the current year
example_two_previous_years <- monthly_response(
  response = data_MVA,
  env_data = LJ_monthly_temperatures,
  method = "cor",
  fixed_width = 3,
```

```
  row_names_subset = TRUE,
  previous_year = TRUE,
  number_previous_years = 2,
  month_interval = c(-1, 10),
  aggregate_function = "mean"
)

# Example with climate detrending, following dplR::detrend().
# LJ_monthly_temperatures are temperatures in degrees Celsius and therefore
# cross zero, so differences must be used instead of the default ratios.
example_detrended <- monthly_response(response = data_MVA,
  env_data = LJ_monthly_temperatures,
  method = "cor", row_names_subset = TRUE,
  remove_insignificant = FALSE,
  dc_method = "Spline", dc_difference = TRUE)

# example_detrended$detrending

# Precipitation sums are positive, so the default ratios can be used
example_detrended_ratio <- monthly_response(response = data_MVA,
  env_data = LJ_monthly_precipitation, tidy_env_data = TRUE,
  method = "cor", row_names_subset = TRUE,
  aggregate_function = "sum", remove_insignificant = FALSE,
  dc_method = "Friedman")

# Example with SPEI for the black pine site Sezana. The residual
# chronology is built as in Izmir et al. (2024).
SEZ_chron <- dplR::chron(dplR::detrend(SEZ_rwl, method = "Spline",
                                       nyrs = 32, f = 0.5),
                         prewhiten = TRUE)
SEZ_res <- SEZ_chron[!is.na(SEZ_chron$res), "res", drop = FALSE]

monthly_wb <- water_balance(
  prec = data_transform(SEZ_daily_psum, format = "monthly",
                        monthly_aggregate_function = "sum"),
  tmin = data_transform(SEZ_daily_tmin, format = "monthly",
                        monthly_aggregate_function = "mean"),
  tmax = data_transform(SEZ_daily_tmax, format = "monthly",
                        monthly_aggregate_function = "mean"),
  lat = 45.71)

example_spei <- monthly_response(response = SEZ_res,
  env_data = monthly_wb, method = "cor", row_names_subset = TRUE,
  previous_year = TRUE, aggregate_function = "SPEI",
  remove_insignificant = FALSE)

# summary(example_spei)
# plot(example_spei, type = 2)
```

monthly_response_seascorr

monthly_response_seascorr

Description

Function calculates all possible partial correlation coefficients between tree-ring chronology and monthly environmental (usually climate) data. All calculated (partial) correlation coefficients are stored in a matrix. The location of stored correlation 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_seascorr(
  response,
  env_data_primary,
  env_data_control,
  previous_year = FALSE,
  number_previous_years = NULL,
  pcor_method = "pearson",
  remove_insignificant = TRUE,
  remove_insignificant_method = "alpha",
  perm_n = 999,
  cluster_threshold = "nominal",
  lower_limit = 1,
  upper_limit = 12,
  fixed_width = 0,
  alpha = 0.05,
  row_names_subset = FALSE,
  reference_window = "start",
  aggregate_function_env_data_primary = "mean",
  quantile_prob_env_data_primary = 0.5,
  aggregate_function_env_data_control = "mean",
  quantile_prob_env_data_control = 0.5,
  temporal_stability_check = "sequential",
  k = 2,
  k_running_window = 30,
  subset_years = NULL,
  ylimits = NULL,
  seed = NULL,
  tidy_env_data_primary = FALSE,
  tidy_env_data_control = FALSE,
  boot = FALSE,
  boot_n = 1000,
  boot_ci_type = "norm",
  boot_conf_int = 0.95,
  month_interval = NULL,
```

```
  dc_method = NULL,
  dc_nyrs = NULL,
  dc_f = 0.5,
  dc_difference = FALSE,
  dc_span = "cv",
  dc_bass = 0,
  dc_scale = NULL,
  dc_env_data_control = NULL,
  pcor_na_use = "everything",
  pcor_control = FALSE
)
```

Arguments

response	a data frame with tree-ring proxy variable and (optional) years as row names. Row.names should be matched with those from env_data_primary and env_data_control data frame. If not, set the row_names_subset argument to TRUE.
env_data_primary	primary 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. Row.names should be matched with those from the response data frame. If not, set the argument row_names_subset to TRUE. Alternatively, env_data_primary could be a tidy data with three columns, i.e. Year, 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_primary to TRUE.
env_data_control	a data frame of monthly sequences of environmental data as columns and years as row names. This data is used as control for calculations of partial correlation coefficients. Each row represents a year and each column represents a day of a year. Row.names should be matched with those from the response data frame. If not, set the row_names_subset argument to TRUE. Alternatively, env_data_control could be a tidy data with three columns, i.e. Year, 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_control to TRUE.
previous_year	logical. If TRUE, previous-year climate data are included in the analysis. If FALSE, no previous-year climate data are included and number_previous_years is ignored.
number_previous_years	integer between 1 and 5 specifying how many previous years should be included in the environmental matrices when previous_year = TRUE. For example, number_previous_years = 2 uses climate data from years t - 2, t - 1 and t for response year t. If NULL and previous_year = TRUE, one previous year is included.
pcor_method	a character string indicating which partial correlation coefficient is to be computed. One of "pearson" (default), "kendall", or "spearman", can be abbreviated.

`remove_insignificant`
: if set to TRUE, removes all partial correlations that do not meet the criterion set by remove_insignificant_method.

`remove_insignificant_method`
: the criterion used when remove_insignificant = TRUE. One of "alpha" (per-window significance threshold; the default), "boot" (bootstrap confidence interval excludes zero; requires boot = TRUE), "fdr_BY" (false discovery rate, Benjamini-Yekutieli, valid under arbitrary dependence between windows), "fdr_BH" (Benjamini-Hochberg, valid under positive dependence and less conservative), "maxstat" (max-statistic permutation test), "sidak" (Sidak correction on the effective number of tests) or "cluster" (cluster-extent inference). The "alpha" and "boot" criteria are applied per window and therefore do not account for the number of windows screened; the remaining criteria do. Degrees of freedom account for the control variable throughout.

  "maxstat" builds a null distribution of the largest absolute partial correlation obtained anywhere in the search by repeatedly shuffling the response, and retains only windows exceeding the resulting threshold. It makes no distributional assumptions but requires perm_n re-evaluations of the whole search.

  "sidak" targets the same family-wise error rate but estimates it analytically and requires no permutations. The effective number of independent tests among the screened primary windows is obtained from the eigenvalues of their correlation matrix following Li and Ji (2005), and a Sidak correction is applied to that number rather than to the nominal count of windows. Years that are missing in some of the windows, such as the first years removed by dc_method = "Ar", are left out of this estimate, rather than the windows themselves.

  "sidak" is an approximation to "maxstat", and a rougher one for partial correlations than for ordinary ones, because the null distribution also depends on the control series. Across 54 combinations of site and primary/control pairing the two thresholds agreed to within 0.020 on average, with a maximum discrepancy of 0.046. The approximation is close to exact when the primary variable is strongly autocorrelated (mean error -0.005 for temperature controlling for precipitation) and permissive when it is not (mean error -0.031 for precipitation controlling for temperature), because the eigenvalue approach does not represent temporal autocorrelation. "maxstat" is therefore preferable for final results, while "sidak" suits exploratory work.

  "cluster" is cluster-extent inference, adapted from neuroimaging. The surface is thresholded at cluster_threshold, connected regions of supra-threshold windows are identified, and each region's mass, the sum of absolute partial correlations inside it, is compared against the largest mass arising in permuted surfaces. It controls the family-wise error rate over CLUSTERS rather than over windows, so it establishes that a region contains signal without identifying which windows within it carry it.

  In tree-ring response surfaces this method has little discriminating power. A real climate signal forms one large connected region whose mass greatly exceeds anything the permuted surfaces produce, so every cluster that forms is usually retained and the permutation step rarely rejects. The number of windows kept is then determined by cluster_threshold rather than by the data. It is provided for completeness and comparison; "maxstat" or "sidak" are preferable when the

question is which windows carry signal.

`perm_n` number of permutations used when remove_insignificant_method = "maxstat". Defaults to 999. Ignored by all other criteria.

`cluster_threshold`
the absolute partial correlation at which clusters are formed when remove_insignificant_method = "cluster". Either "nominal", the default, which uses the critical correlation at the chosen alpha, or a single number between 0 and 1. This is a free parameter and it largely determines how many windows are retained, so the value used is reported in $significance_filter. Ignored by all other criteria.

`lower_limit` lower limit of window width (i.e. number of consecutive months to be used for calculations)

`upper_limit` upper limit of window width (i.e. number of consecutive months to be used for calculations)

`fixed_width` fixed width used for calculations (i.e. number of consecutive months to be used for calculations)

`alpha` significance level used to remove insignificant calculations.

`row_names_subset`
if set to TRUE, row.names are used to subset env_data_primary, env_data_control and response data frames. Only years from all three data frames are kept.

`reference_window`
character string, the reference_window argument describes, how each calculation is referred. There are two different options: 'start' (default) and 'end'. If the reference_window argument is set to 'start', then each calculation is related to the starting month of window. If the reference_window argument is set to 'end', then each calculation is related to the ending day of window calculation.

`aggregate_function_env_data_primary`
character string specifying how the monthly data from env_data_primary should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'quantile' and 'SPEI'. Missing months are skipped, so 'sum' adds only the months that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index of each window from the monthly climatic water balance (precipitation minus potential evapotranspiration, see water_balance()) in env_data_primary, as described for aggregate_function in monthly_response(). A window that includes a missing month is NA in that year.

`quantile_prob_env_data_primary`
numeric value between 0 and 1 specifying the quantile probability used when aggregate_function_env_data_primary = 'quantile'. For example, 0.95 calculates the 95th percentile. The default is 0.5.

`aggregate_function_env_data_control`
character string specifying how the monthly data from env_data_control should be aggregated. The default is 'mean', the other options are 'median', 'sum', 'quantile' and 'SPEI'. Missing months are skipped, so 'sum' adds only the months that are available; a window without any value is NA. 'SPEI' calculates the Standardized Precipitation-Evapotranspiration Index of each window

from the monthly climatic water balance (precipitation minus potential evapotranspiration, see water_balance()) in env_data_control, as described for aggregate_function in monthly_response(). A window that includes a missing month is NA in that year.

`quantile_prob_env_data_control`
: numeric value between 0 and 1 specifying the quantile probability used when aggregate_function_env_data_control = 'quantile'. For example, 0.95 calculates the 95th percentile. The default is 0.5.

`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

`k_running_window`
: the length of running window for temporal stability check. Applicable only if temporal_stability argument is set to running window.

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

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

`seed`
: optional seed argument for reproducible results

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

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

`boot`
: logical, if TRUE, bootstrap confidence intervals are calculated for the partial correlation coefficients and returned as $boot_lower and $boot_upper. The coefficients themselves are those of the observed data, as with boot = FALSE. Versions before 2.0.0 reported the mean of the bootstrap replicates instead.

`boot_n`
: The number of bootstrap replicates

`boot_ci_type`
: A character string representing the type of bootstrap intervals: "norm" (default), "basic", "perc" or "bca". "bca" needs boot_n of at least the number of analysed years. With fewer replicates boot::boot.ci() cannot estimate bca intervals, so they are all NA, and a warning is given. Studentized intervals ("stud") are not available.

`boot_conf_int`
: A scalar or vector containing the confidence level(s) of the required interval(s)

`month_interval`
: a vector of two values defining the interval of months used for calculations. Positive values indicate months in the current year. Negative values indicate months in the previous-year block and are used only when previous_year = TRUE. If

previous_year = FALSE and negative values are supplied, month_interval is ignored and the analysis is performed for the current year only using month_interval = c(1, 12). If number_previous_years > 1, the previous-year block starts with the earliest included previous year. For example, previous_year = TRUE, number_previous_years = 2 and month_interval = c(-1, 12) analyses the full sequence from January of year t - 2 to December of year t.

`dc_method` a character string specifying how the aggregated climate series of each moving window should be detrended before the partial correlation is calculated. Detrending is applied to the aggregated series, i.e. to a vector with one value per year, and not to the raw monthly data. By default the same detrending is applied to the windows of env_data_primary and env_data_control; see dc_env_data_control to detrend the control windows differently. Possible values are "none" (or NULL, the default, no detrending), "SLD" (Simple Linear Detrending, the historical dendroTools option), and the smoothers "Spline", "Mean", "Ar" and "Friedman", which follow dplR::detrend(). The smoothers are fitted in chronological order of the years given by the row names. "Ar" (prewhitening) leaves missing values at the start of each detrended window, so pcor_na_use is changed to "pairwise.complete.obs", with a warning, unless it already excludes missing values. The growth-specific options of dplR::detrend() ("ModNegExp", "ModHugershoff", "AgeDepSpline") are not available, because they assume strictly positive series with a biological growth trend.

`dc_nyrs` a number giving the rigidity of the smoothing spline when dc_method = "Spline". Defaults to NULL, i.e. 0.67 times the length of the series, exactly as in dplR::detrend(). Ignored by the other methods.

`dc_f` a number between 0 and 1 giving the frequency response at the wavelength given by dc_nyrs when dc_method = "Spline". Defaults to 0.5. Ignored by the other methods.

`dc_difference` logical. If FALSE (default, as in dplR::detrend()), the detrended series is calculated as a ratio between the observed series and the fitted curve. If TRUE, it is calculated as a difference. Ratio detrending is only defined for strictly positive data, such as precipitation sums, so the function stops if a data frame whose windows are detrended by ratios, env_data_primary or env_data_control, contains negative values. Windows whose aggregated series still contains a zero, for example a completely dry month, are returned as NA. For temperature and for any other variable that can be negative, use dc_difference = TRUE. Ignored when dc_method = "SLD", which is always residual based.

`dc_span` the span used by the Friedman super smoother when dc_method = "Friedman". Either "cv" (default, cross-validation) or a number between 0 and 1. See also stats::supsmu(). Ignored by the other methods.

`dc_bass` a number between 0 and 10 controlling the smoothness of the Friedman super smoother when dc_method = "Friedman". Defaults to 0. See also stats::supsmu(). Ignored by the other methods.

`dc_scale` logical or NULL. If TRUE, the detrended series is divided by the standard deviation of its own values. The default (NULL) uses the convention of the selected method: TRUE for dc_method = "SLD", which preserves the behaviour of earlier dendroTools versions, and FALSE for the dplR methods, which are

not rescaled in dplR::detrend(). Rescaling does not affect partial correlations, but it does affect the scale of $optimized_return and of the transfer function.

`dc_env_data_control`
: NULL (default) or a named list of detrending settings for the windows of env_data_control. With NULL, the control windows are detrended exactly like the primary windows. A list replaces any of dc_method, dc_nyrs, dc_f, dc_difference, dc_span, dc_bass and dc_scale for the control windows only, and the settings it does not name are taken from the arguments above. For example, dc_method = "Spline", dc_difference = TRUE and dc_env_data_control = list(dc_difference = FALSE) detrend temperature (primary) by differences and precipitation (control) by ratios, and dc_env_data_control = list(dc_method = "none") leaves the control windows untouched.

`pcor_na_use`
: an optional character string giving a method for computing covariances in the presence of missing values for partial correlation coefficients. This must be (an abbreviation of) one of the strings "all.obs", "everything" (default), "complete.obs", "na.or.complete", or "pairwise.complete.obs". See also the documentation for the base partial.r in psych R package

`pcor_control`
: logical. If TRUE, the partial correlations of the response with the control variable, controlling for the primary variable, are also calculated for every window. They are what the function returns when env_data_primary and env_data_control, and their settings, are swapped. They are filtered with the same significance method and settings as the primary partial correlations, with permutation methods against the same permutations, and returned as $calculations_control. plot(x, type = 3) shows them as a heatmap, and summary() also reports the strongest of them, its window, and the value in the optimal window of the primary variable. The primary results do not change. Default is FALSE.

Value

a list with elements including:

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 there are no row names, this argument is given as NA
5. $optimized_return - data frame with two columns, response variable and aggregated (averaged) monthly data that return the optimal results. This data.frame could be directly used to calibrate a model for climate reconstruction
6. $optimized_return_all - a data frame with aggregated monthly data, that returned the optimal result for the entire env_data_primary (and not only subset of analysed years)
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 - not available for partial correlation method

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. $type - the character string describing type of analysis: monthly or monthly
13. $reference_window - character string, which reference window was used for calculations
14. $boot_lower - matrix with lower limits of bootstrap confidence intervals
15. $boot_upper - matrix with upper limits of bootstrap confidence intervals
16. $aggregated_climate_primary - matrix with all aggregated climate series of primary data
17. $aggregated_climate_control - matrix with all aggregated climate series of control data
18. $significance_filter - list describing which significance filter was applied, the criterion used, and how many matrix cells were retained or removed
19. $previous_year - logical indicating whether previous-year climate data were used
20. $number_previous_years - integer indicating how many previous years were used
21. $detrending - information about the climate detrending applied, a list with the elements primary and control, each giving the method and the settings used for those windows, or "none"
22. $variance_partitioning - a data frame for the optimal window: the correlations of the response with the primary and the control series and between them (r_response_primary, r_response_control, r_primary_control), both partial correlations (pcor_primary, pcor_control), the variance of the response explained by both series together (r_squared) and how it splits into a part unique to the primary series (unique_primary), a part unique to the control series (unique_control) and a part they share (shared, negative when one series suppresses the other). For pcor_method = "spearman" the split refers to ranks; for "kendall" it is NA
23. with pcor_control = TRUE: $calculations_control - a matrix with the partial correlations of the response with the control variable, controlling for the primary variable; $boot_lower_control and $boot_upper_control - their bootstrap confidence intervals; $significance_filter_control - the significance filter applied to them; $plot_heatmap_control - their heatmap, also shown by plot(x, type = 3)

Examples

```
# 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_monthly_temperatures)
data(LJ_monthly_precipitation)

# 1 Basic example
example_basic <- monthly_response_seascorr(response = data_MVA,
   fixed_width = 11,
   env_data_primary = LJ_monthly_temperatures,
```

```
   env_data_control = LJ_monthly_precipitation,
   row_names_subset = TRUE,
   remove_insignificant = TRUE,
   reference_window = "start",
   aggregate_function_env_data_primary = 'median',
   aggregate_function_env_data_control = 'median',
   alpha = 0.05, pcor_method = "spearman",
   tidy_env_data_primary = FALSE,
   tidy_env_data_control = TRUE,
   previous_year = TRUE)

# summary(example_basic)
# plot(example_basic, type = 1)
# plot(example_basic, type = 2)
# example_basic$optimized_return
# example_basic$optimized_return_all
# example_basic$temporal_stability

# 2 Extended example
example_extended <- monthly_response_seascorr(response = data_MVA,
   env_data_primary = LJ_monthly_temperatures,
   env_data_control = LJ_monthly_precipitation,
   row_names_subset = TRUE, dc_method = "SLD",
   remove_insignificant = FALSE,
   aggregate_function_env_data_primary = 'mean',
   aggregate_function_env_data_control = 'mean',
   alpha = 0.05, pcor_na_use = "everything",
   reference_window = "end",
   tidy_env_data_primary = FALSE,
   tidy_env_data_control = TRUE)

# summary(example_extended)
# plot(example_extended, type = 1)
# plot(example_extended, type = 2)
# example_extended$optimized_return
# example_extended$optimized_return_all

# 3 Example using quantiles for primary and control variables
example_quantile <- monthly_response_seascorr(
   response = data_MVA,
   env_data_primary = LJ_monthly_temperatures,
   env_data_control = LJ_monthly_precipitation,
   row_names_subset = TRUE,
   fixed_width = 3,
   previous_year = TRUE,
   aggregate_function_env_data_primary = "quantile",
   quantile_prob_env_data_primary = 0.50,
   aggregate_function_env_data_control = "quantile",
   quantile_prob_env_data_control = 0.50,
   tidy_env_data_primary = FALSE,
   tidy_env_data_control = TRUE)

 # summary(example_quantile)
```

```
# 4 Example with climate detrending, following dplR::detrend(). The same
# detrending is applied to the primary and the control windows (see
# dc_env_data_control to set it separately). The temperatures cross zero,
# so differences are used instead of ratios.
example_detrended <- monthly_response_seascorr(response = data_MVA,
   env_data_primary = LJ_monthly_temperatures,
   env_data_control = LJ_monthly_precipitation,
   row_names_subset = TRUE,
   remove_insignificant = FALSE,
   tidy_env_data_primary = FALSE,
   tidy_env_data_control = TRUE,
   dc_method = "Friedman", dc_difference = TRUE)

# example_detrended$detrending

# 5 Partial correlations with both variables: temperature controlling for
# precipitation, and precipitation controlling for temperature
example_both <- monthly_response_seascorr(response = data_MVA,
   env_data_primary = LJ_monthly_temperatures,
   env_data_control = LJ_monthly_precipitation,
   row_names_subset = TRUE,
   remove_insignificant = FALSE,
   tidy_env_data_primary = FALSE,
   tidy_env_data_control = TRUE,
   pcor_control = TRUE)

# summary(example_both)
# example_both$variance_partitioning
# plot(example_both, type = 3)
```

`SEZ_daily_climate` *Daily climate data for the black pine site Sezana (SEZ), 1950 - 2020*

Description

Daily minimum, mean and maximum temperatures and daily precipitation sums for the black pine site Sezana (SEZ) in Slovenia, whose raw ring widths are in `SEZ_rwl`. The data are from the gridded E-OBS dataset, version 25.0e, on a 0.1 degree regular grid, extracted for the grid point nearest to the site (lon = 13.85, lat = 45.75), as in Izmir et al. (2024). Temperatures are given to 0.01 degrees Celsius and precipitation to 0.1 mm, the precision of E-OBS.

Format

Four data frames with 25933 rows, one for each day from 1 January 1950 to 31 December 2020, and 2 variables:

date the date (class Date)

t_min, t_avg, t_max, p_sum the minimum (SEZ_daily_tmin), mean (SEZ_daily_tavg) and maximum (SEZ_daily_tmax) temperature in degrees Celsius, and the precipitation sum (SEZ_daily_psum) in mm

Details

The data have one row per day. `data_transform` converts them into the daily (366 columns) or monthly (12 columns) layout of `daily_response` and `monthly_response`, and `water_balance` calculates the climatic water balance needed for aggregate_function = "SPEI".

The E-OBS data are subject to the ECA&D data policy: they may only be used for non-commercial research and non-commercial education.

We acknowledge the E-OBS dataset from the EU-FP6 project UERRA (https://www.uerra.eu) and the Copernicus Climate Change Service, and the data providers in the ECA&D project (https://www.ecad.eu). Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200

Source

https://www.ecad.eu/download/ensembles/download.php

References

Izmir, S.C., Jevsenak, J., Krajnc, L., Hafner, P., Kose, N. (2024) Distinct spatial patterns in climate-growth relationships, vegetation and resilience indices of Black pine (Pinus nigra J.F. Arnold) from its northern and southern distribution range. Dendrochronologia, 88, 126236. doi:10.1016/j.dendro.2024.126236

Examples

```
# daily layout: years as rows, days of year as columns
daily_tavg <- data_transform(SEZ_daily_tavg, format = "daily")
daily_tavg[1:5, 1:5]

# monthly precipitation sums
monthly_psum <- data_transform(SEZ_daily_psum, format = "monthly",
                               monthly_aggregate_function = "sum")
round(colMeans(monthly_psum), 1)
```

SEZ_rwl *Raw tree-ring widths of black pine from Sezana (SEZ), Slovenia, 1882 - 2021*

Description

Raw tree-ring widths of 41 cores from 21 black pine trees (*Pinus nigra* subsp. *nigra*) from the site Sezana (SEZ) on the Karst plateau in western Slovenia (45.71 N, 13.88 E, 532 m a.s.l.). The site is sub-Mediterranean, on dolomite bedrock, and tree growth there is limited by precipitation (Izmir et al. 2024). The trees were cored at breast height after the 2021 growing season, with two cores per tree. One core of tree 14 could not be cross-dated and is not included. Daily climate data for the site are in `SEZ_daily_climate`.

Usage

```
SEZ_rwl
```

Format

An object of class "rwl" (a data frame, see dplR::read.rwl()) with 140 rows, the years 1882 - 2021 as row names, and 41 columns, one per core. Ring widths are in mm.

Details

Izmir et al. (2024) detrended every series with a 32-year spline with a frequency response of 0.5 and averaged the prewhitened indices with a biweight robust mean, which gives the residual chronology (see the examples).

Source

The measurements of Izmir et al. (2024).

References

Izmir, S.C., Jevsenak, J., Krajnc, L., Hafner, P., Kose, N. (2024) Distinct spatial patterns in climate-growth relationships, vegetation and resilience indices of Black pine (Pinus nigra J.F. Arnold) from its northern and southern distribution range. Dendrochronologia, 88, 126236. doi:10.1016/j.dendro.2024.126236

Examples

```
dim(SEZ_rwl)

# the residual chronology of Izmir et al. (2024)
SEZ_rwi <- dplR::detrend(SEZ_rwl, method = "Spline", nyrs = 32, f = 0.5)
SEZ_chron <- dplR::chron(SEZ_rwi, prewhiten = TRUE)
head(SEZ_chron[!is.na(SEZ_chron$res), ])
```

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:

TRWi Standardised tree-ring width chronology

Source

https://www.ncei.noaa.gov/access/paleo-search/study/14108

swit272_daily_precipitation *Daily precipitation for swit272 chronology*

Description

Sum of daily precipitation in millimeters for the period 1950 - 2019. This gridded E-OBS data on 0.1° regular grid, version 20e. Extracted data is for the grid point with lon = 9.75 and lat = 46.45.

Usage

```
swit272_daily_precipitation
```

Format

A data frame with 25414 rows and 2 variables:

date date as a factor, Year-Month-Day

p_sum daily precipitation sum in mm

Details

The E-OBS data are subject to the ECA&D data policy: they may only be used for non-commercial research and non-commercial education.

We acknowledge the E-OBS dataset from the EU-FP6 project UERRA (http://www.uerra.eu) and the Copernicus Climate Change Service, and the data providers in the ECA&D project (https://www.ecad.eu). Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200

Source

https://www.ecad.eu/download/ensembles/download.php

---

swit272_daily_temperatures

Daily temperatures for swit272 chronology

Description

Mean daily temperature in Celsius for the period 1950 - 2019. This gridded E-OBS data on 0.1° regular grid, version 20e. Extracted data is for the grid point with lon = 9.75 and lat = 46.45.

Usage

```
swit272_daily_temperatures
```

Format

A data frame with 25414 rows and 2 variables:

date date as a factor, Year-Month-Day

t_avg mean daily temperature in degrees Celsius

Details

The E-OBS data are subject to the ECA&D data policy: they may only be used for non-commercial research and non-commercial education.

We acknowledge the E-OBS dataset from the EU-FP6 project UERRA (http://www.uerra.eu) and the Copernicus Climate Change Service, and the data providers in the ECA&D project (https://www.ecad.eu). Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., 123. doi:10.1029/2017JD028200

Source

https://www.ecad.eu/download/ensembles/download.php

`water_balance` *Climatic water balance from temperature and precipitation*

Description

Calculates the climatic water balance, i.e. precipitation minus potential evapotranspiration (P - PET), from daily or monthly precipitation and minimum and maximum temperatures. The result is the input for `aggregate_function = "SPEI"` in `daily_response`, `monthly_response`, `daily_response_seascorr` and `monthly_response_seascorr`. PET is estimated with the Hargreaves equation (Hargreaves and Samani 1985; Allen et al. 1998), using the equations of `SPEI::hargreaves()`.

Usage

```
water_balance(prec, tmin, tmax, lat, tmean = NULL)
```

Arguments

`prec`, `tmin`, `tmax`	data frames of precipitation sums (mm) and of minimum and maximum temperatures (degrees Celsius), with years as row names. Daily data have 366 columns, one per day of year (DOY); monthly data have 12 columns, January to December. This is the layout of env_data in `daily_response` and `monthly_response`; daily data with a date column can be converted with `data_transform`. All data frames must have the same dimensions and row names, and for monthly data the row names must be calendar years.
`lat`	latitude of the site in decimal degrees, negative in the southern hemisphere
`tmean`	optional data frame of mean temperatures in the same layout. If NULL (default), the mean temperature is (tmin + tmax) / 2, as in `SPEI::hargreaves()`.

Details

Daily PET (mm per day) is

$$PET = 0.0023 \cdot 0.408 \cdot R_a(T_{mean} + 17.8)\sqrt{T_{max} - T_{min}}$$

where R_a is the extraterrestrial radiation of the day of year (MJ m-2 day-1) and 0.408 converts it into mm of evaporation per day (Allen et al. 1998, equations 20, 21 and 52). For monthly data, the same equation is applied to the middle day of each month and multiplied by the number of days of the month, which gives the values of `SPEI::hargreaves()` for a monthly time series. Negative temperature ranges and negative PET are set to 0. Beyond the polar circles, the sunset hour angle is pi during the polar day and 0 during the polar night (`SPEI::hargreaves()` uses the largest angle of the series for the polar day). Missing values are kept missing.

Value

a data frame of the climatic water balance (mm), with the dimensions, row names and column names of prec

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. FAO, Rome.

Hargreaves, G.H., Samani, Z.A. (1985) Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2), 96-99.

Begueria, S., Vicente-Serrano, S.M. (2023) SPEI: Calculation of the Standardized Precipitation-Evapotranspiration Index. R package version 1.8.1.

Examples

```
# daily climatic water balance of the black pine site Sezana
prec <- data_transform(SEZ_daily_psum, format = "daily")
tmin <- data_transform(SEZ_daily_tmin, format = "daily")
tmax <- data_transform(SEZ_daily_tmax, format = "daily")
tmean <- data_transform(SEZ_daily_tavg, format = "daily")

wb <- water_balance(prec = prec, tmin = tmin, tmax = tmax, lat = 45.71,
                    tmean = tmean)
wb[1:5, 1:5]

# monthly climatic water balance
monthly_wb <- water_balance(
  prec = data_transform(SEZ_daily_psum, format = "monthly",
                        monthly_aggregate_function = "sum"),
  tmin = data_transform(SEZ_daily_tmin, format = "monthly",
                        monthly_aggregate_function = "mean"),
  tmax = data_transform(SEZ_daily_tmax, format = "monthly",
                        monthly_aggregate_function = "mean"),
  lat = 45.71)
round(colMeans(monthly_wb), 1)
```

---

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")
```

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