Package 'ffaframework'

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Title Flood Frequency Analysis Framework

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Description Tools for exploratory data analysis and flood frequency analysis. Implements statistical tests and methods for distribution selection, parameter estimation, uncertainty quantification, and model assessment.

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Contents

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ams_decomposition   *Decompose Annual Maximum Streamflow Data*

Description

Removes trends in the mean and/or variance of annual maximum streamflow (AMS) data using
Sen's trend estimator and/or a moving-window estimator of the variance. Four scenarios are supported:

1. No trend. The data is returned unmodified.

2. Trend in the mean only.

3. Trend in the variance only.

4. Trends in both the mean and the variance.

Usage

```
ams_decomposition(data, years, trend)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
years	Numeric vector of observation years corresponding to data. Must be the same length as data and strictly increasing.
trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- location: Logical scalar. If TRUE, the location parameter has a trend.
- scale: Logical scalar. If TRUE, the scale parameter has a trend.

Details

Internally, the function does the following:

1. Compute `covariate = (years - 1900) / 100`.

2. If there is a trend in the location, fit Sen's trend estimator to `data` and `covariate`. Then, remove the fitted linear trend.

3. If there is a trend in the scale, compute the moving-window variance using ams_mw_variance, fit Sen's trend estimator to those variances, and then rescales the series to remove trends in the scale.

4. If necessary, shift the data so that its minimum is at least 1.

Value

Numeric vector of decomposed AMS data with the same length as `data`.

See Also

ams_mw_variance, eda_sens_trend

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
trend <- list(location = TRUE, scale = FALSE)
ams_decomposition(data, years, trend)
```

---

ams_mw_variance   *Estimate Variance for Annual Maximum Streamflow Data*

Description

This function estimates the standard deviation of a vector of annual maximum streamflow (AMS) data using a moving window algorithm, returning a list that pairs each window's mean year with its computed standard deviation. The parameters `size` and `step` parameters control the behaviour of the window.

Usage

```
ams_mw_variance(data, years, size = 10, step = 5)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
`size`	Integer scalar. The number of years in each moving window. Must be a positive number less than or equal to `length(data)` (default is 10). If `length(data)` `< size`, an error is raised.
`step`	Integer scalar. The offset (in years) between successive moving windows. Must be a positive number (default is 5).

Value

A list with two entries:

- `years`: Numeric vector containing the mean year within each window.

- `std`: Numeric vector of standard deviations within each window.

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
ams_mw_variance(data, years)
```

`eda_bbmk_test`	*Block-Bootstrap Mann-Kendall Test for Trend Detection*

Description

Performs a bootstrapped version of the Mann-Kendall trend test to account for serial correlation in annual maximum streamflow (AMS) data. The procedure uses Spearman's autocorrelation test to estimate the least insignificant lag, then applies a bootstrap procedure to obtain the empirical p-value and confidence bounds for the Mann-Kendall S-statistic.

Usage

```
eda_bbmk_test(data, alpha = 0.05, samples = 10000L, quiet = TRUE)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`samples`	Integer scalar. The number of bootstrap samples. Default is 10000.
`quiet`	Logical scalar. If `FALSE`, prints a summary of of the statistical test to the console. Default is `TRUE`.

Details

The block size for the bootstrap is selected as `least_lag + 1`, where `least_lag` is estimated using eda_spearman_test. Each bootstrap sample is generated by resampling blocks of the original data (without replacement) and computing the Mann-Kendall S-statistic. This procedure adjusts for autocorrelation in the data.

Value

List; the results of the test, including:

- `data`: The `data` argument.
- `s_bootstrap`: Vector of bootstrapped test statistics used for plotting.
- `s_statistic`: The Mann-Kendall test statistic computed on the original series.
- `p_value`: Empirical two-sided p-value computed from the bootstrap distribution.
- `bounds`: Confidence interval bounds for the null distribution of the statistic.
- `reject`: Logical. If `TRUE`, the null hypothesis was rejected at `alpha`.
- `msg`: Character string summarizing the test result (printed if `quiet = FALSE`).

See Also

plot_bbmk_test, eda_mk_test, eda_spearman_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
eda_bbmk_test(data, samples = 1000L)
```

---

eda_kpss_test	*Kwiatkowski–Phillips–Schmidt–Shin (KPSS) Unit Root Test*

Description

Performs the KPSS unit root test on annual maximum streamflow (AMS) data. The null hypothesis is that the time series is trend-stationary with a linear trend and constant drift. The alternative hypothesis is that the time series has a unit root and is non-stationary.

Usage

```
eda_kpss_test(data, alpha = 0.05, quiet = TRUE)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`quiet`	Logical scalar. If `FALSE`, prints a summary of of the statistical test to the console. Default is `TRUE`.

Details

The implementation of the KPSS test is based on the **aTSA** package, which interpolates a significance table from Hobjin et al. (2004). Therefore, a result of $p = 0.01$ implies that $p \leq 0.01$ and a result of $p = 0.10$ implies that $p \geq 0.10$. This implementation uses the Type III KPSS test, which accounts for a linear trend in the data.

Value

A list containing the test results, including:

- `data`: The `data` argument.

- `statistic`: The KPSS test statistic.

- `p_value`: The interpolated p-value. See note regarding discrete thresholds.

- `reject`: Logical scalar. If, TRUE the null hypothesis is rejected at `alpha`.

- `msg`: Character string summarizing the test outcome, printed if `quiet = FALSE`.

References

Hobijn, B., Franses, P.H. and Ooms, M. (2004), Generalizations of the KPSS-test for stationarity. Statistica Neerlandica, 58: 483-502.

See Also

eda_pp_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
eda_kpss_test(data)
```

---

eda_mks_test   *Mann–Kendall–Sneyers Test for Change Point Detection*

Description

Performs the Mann–Kendall–Sneyers (MKS) test to detect the beginning of a monotonic trend in annual maximum streamflow (AMS) data. The test computes normalized progressive and regressive Mann–Kendall statistics and identifies statistically significant crossing points, indicating potential change points in the trend.

Usage

```
eda_mks_test(data, years, alpha = 0.05, quiet = TRUE)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`quiet`	Logical scalar. If `FALSE`, prints a summary of of the statistical test to the console. Default is `TRUE`.

Details

The function computes progressive and regressive Mann–Kendall statistics S_t, normalized by their expected values and variances under the null hypothesis. The crossing points where the difference between these normalized statistics changes sign are identified using linear interpolation. The significance of detected crossings is assessed using quantiles of the normal distribution.

Value

A list containing the test results, including:

- `data`: The `data` argument.
- `years`: The `years` argument.
- `s_progressive`: Normalized progressive Mann–Kendall-Sneyers statistics.
- `s_regressive`: Normalized regressive Mann–Kendall-Sneyers statistics.
- `bound`: Critical confidence bound for significance based on `alpha`.
- `crossing_df`: Crossing points, including indices, years, statistics, and AMS.
- `change_df`: Subset of `crossing.df` with statistically significant crossings.
- `p_value`: Two-sided p-value derived from the maximum crossing statistic.
- `reject`: Logical. If `TRUE`, the null hypothesis of no change point is rejected.
- `msg`: Character string summarizing the test result (printed if `quiet = FALSE`).

References

Sneyers, R. (1990). On the statistical analysis of series of observations. Technical note No. 143, World Meteorological Organization, Geneva.

See Also

plot_mks_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
eda_mks_test(data, years)
```

---

eda_mk_test   *Mann–Kendall Trend Test*

Description

Performs the Mann–Kendall trend test on a numeric vector to detect the presence of a monotonic trend (increasing or decreasing) over time. The test is non-parametric and accounts for tied observations in the data. The null hypothesis assumes there is no monotonic trend.

Usage

```
eda_mk_test(data, alpha = 0.05, quiet = TRUE)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`quiet`	Logical scalar. If `FALSE`, prints a summary of of the statistical test to the console. Default is `TRUE`.

Details

The statistic S is computed as the sum over all pairs $i < j$ of the sign of the difference $x_j - x_i$. Ties are explicitly accounted for when calculating the variance of S, using grouped frequencies of tied observations. The test statistic Z is then computed based on the sign and magnitude of S, and the p-value is derived from the standard normal distribution.

Value

A list containing the test results, including:

- `data`: The `data` argument.
- `s_statistic`: The Mann–Kendall test statistic S.
- `s_variance`: The variance of the test statistic under the null hypothesis.
- `p_value`: The p-value associated with the two-sided hypothesis test.
- `reject`: Logical. If `TRUE`, the null hypothesis is rejected at `alpha`.
- `msg`: A character string summarizing the result, printed if `quiet = FALSE`.

See Also

eda_bbmk_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
eda_mk_test(data)
```

eda_pettitt_test	*Pettitt Test for Abrupt Changes in the Mean of a Time Series*

Description

Performs the non-parametric Pettitt test to detect a single change point in the mean of a time series, used to identify abrupt shifts in hydrological data.

Usage

```
eda_pettitt_test(data, years, alpha = 0.05, quiet = TRUE)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
years	Numeric vector of observation years corresponding to data. Must be the same length as data and strictly increasing.
alpha	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
quiet	Logical scalar. If FALSE, prints a summary of of the statistical test to the console. Default is TRUE.

Details

The Pettitt test is a rank-based non-parametric test that evaluates the hypothesis of a change point in the mean of a time series. It computes the maximum of the absolute value of the U-statistic over all possible split points. The p-value is approximated using an asymptotic formula.

Value

A list containing the test results, including:

- data: The data argument.
- years: The years argument.
- u_t: Numeric vector of absolute U-statistics for all time indices.
- k_statistic: Numeric scalar.Tthe maximum absolute U-statistic.
- k_critical: Numeric scalar. The critical K-statistic value for given alpha.
- p_value: Numeric scalar. Approximate p-value for the test.
- change_index: Integer scalar. Index of the detected change point (0 if none).
- change_year: Integer scalar. Year of the detected change point (0 if none).
- reject: Logical scalar. If TRUE, the null hypothesis was rejected.
- msg: Character scalar. A formatted summary message describing the test result.

See Also

[plot_pettitt_test](#)

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
eda_pettitt_test(data, years)
```

---

eda_pp_test   *Phillips–Perron Unit Root Test*

Description

Applies the Phillips–Perron (PP) test to check for a unit root in annual maximum streamflow (AMS) data. The null hypothesis is that the series contains a unit root (and is thus non-stationary). This implementation of the PP test assumes the time series has both stationary drift and a linear trend.

Usage

```
eda_pp_test(data, alpha = 0.05, quiet = TRUE)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
alpha	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
quiet	Logical scalar. If FALSE, prints a summary of of the statistical test to the console. Default is TRUE.

Details

The implementation of this test is based on the **aTSA** package, which interpolates p-values from a table of critical values presented in Fuller W. A. (1996). The critical values are only available for $\alpha \geq 0.01$. Therefore, a reported p-value of 0.01 indicates $p \leq 0.01$.

Value

List; the test results, consisting of:

- data: The data argument.
- statistic: The Z-statistic used to perform the test.
- p.value: Reported p-value from the test. See notes on interpolation thresholds.
- reject: Logical. If TRUE, the null hypothesis was rejected at alpha.
- msg: Character string summarizing the test result, printed if quiet = FALSE.

References

Fuller, W. A. (1996). Introduction to statistical time series, second ed., Wiley, New York.

See Also

eda_kpss_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
eda_pp_test(data)
```

---

eda_runs_test	*Wald–Wolfowitz Runs Test for Randomness*

Description

Applies the Wald–Wolfowitz runs test to a numeric vector of residuals in order to assess whether they behave as a random sequence. The test statistic's p-value is compared to the significance level `alpha`, and a decision is returned along with a human-readable summary message.

Usage

```
eda_runs_test(results, alpha = 0.05, quiet = TRUE)
```

Arguments

`results`	A fitted linear model produced by [eda_sens_trend]().
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`quiet`	Logical scalar. If `FALSE`, prints a summary of of the statistical test to the console. Default is `TRUE`.

Details

The Wald–Wolfowitz runs test examines the sequence of residuals to test for randomness around the median. A small p-value suggests non-random clustering, which may indicate that a linear model is inappropriate for the data.

Value

A list containing the test results, including:

- `residuals`: Numeric vector of residual values from a fitted linear model.
- `n`: The length of the residuals vector after removing the median.
- `n_plus`, `n_minus`: The number of residuals above/below the median.
- `runs`: The number of runs in the transformed sequence of residuals.
- `statistic`: The runs test statistic, computed using `runs`.
- `p_value`: P-value from the Wald–Wolfowitz runs test applied to residuals.
- `reject`: Logical. If TRUE, the null hypothesis of random residuals is rejected.
- `msg`: Character string summarizing the test result, printed if `quiet = FALSE`.

References

Wald, A. and Wolfowitz, J. (1940). On a test whether two samples are from the same population. Annals of Mathematical Statistics, 11(2), 147–162.

See Also

[plot_runs_test](), [eda_sens_trend]()

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
sens <- eda_sens_trend(data, years)
eda_runs_test(sens)
```

---

eda_sens_trend   *Sen's Trend Estimator*

Description

Computes Sen's trend estimator for a univariate time series.

Usage

```
eda_sens_trend(data, years, quiet = TRUE)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
years	Numeric vector of observation years corresponding to data. Must be the same length as data and strictly increasing.
quiet	Logical scalar. If FALSE, prints a summary of of the statistical test to the console. Default is TRUE.

Details

Sen's slope estimator is a robust, non-parametric trend estimator computed from the median of all pairwise slopes between data points. The corresponding intercept is taken as the median of residual-corrected values.

Value

A list containing the estimated trend:

- data: The data argument.
- years: The years argument.
- slope: Median slope of all pairwise data-year combinations.
- intercept: Median intercept estimate of the fitted line.
- residuals: Vector of residuals between observed and fitted values.
- msg: Character string summarizing the results.

References

Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63(324), 1379–1389.

See Also

eda_runs_test, plot_sens_trend

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
eda_sens_trend(data, years)
```

---

eda_spearman_test   *Spearman Test for Autocorrelation*

Description

Performs the Spearman rank autocorrelation test on annual maximum streamflow (AMS) data to check for autocorrelation at various lags. Reports the smallest lag where the autocorrelation is not statistically significant at the given significance level.

Usage

```
eda_spearman_test(data, alpha = 0.05, quiet = TRUE)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
alpha	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
quiet	Logical scalar. If FALSE, prints a summary of of the statistical test to the console. Default is TRUE.

Details

For each lag from 1 to $n - 3$, the function computes the Spearman correlation coefficient between the AMS series and its lagged version. The first lag with an insignificant autocorrelation coefficient returned as least.lag.

Value

A list containing the test results, including:

- data: The data argument.
- rho: Numeric vector of autocorrelation estimates for lags 1 to $n - 3$.
- sig: Logical vector indicating which lags exhibit significant autocorrelation.
- least.lag: The smallest lag at which the autocorrelation is insignificant.
- reject: Logical. If TRUE, then least.lag > 0.
- msg: Character string summarizing the test result, printed if quiet = FALSE.

See Also

cor.test, eda_bbmk_test, plot_spearman_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
eda_spearman_test(data)
```

---

eda_white_test   *White Test for Heteroskedasticity*

Description

Performs the White test for heteroskedasticity by regressing the squared residuals of a linear model on the original regressors and their squared terms. The null hypothesis is homoskedasticity.

Usage

```
eda_white_test(data, years, alpha = 0.05, quiet = TRUE)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
years	Numeric vector of observation years corresponding to data. Must be the same length as data and strictly increasing.
alpha	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
quiet	Logical scalar. If FALSE, prints a summary of of the statistical test to the console. Default is TRUE.

Details

The White test regresses the squared residuals from a primary linear model lm(data ~ years) against both the original regressor and its square. The test statistic is calculated as nR^2, where R^2 is the coefficient of determination from the auxiliary regression. Under the null hypothesis, this statistic follows a χ^2 distribution with 2 degrees of freedom. Rejection of the null hypothesis suggests heteroskedasticity in the residuals.

Value

A list containing the results of the White test:

- data: The data argument.
- years: The years argument.
- r_squared: Coefficient of determination from the auxiliary regression.
- statistic: White test statistic based on sample size and r.squared.
- p_value: The p-value derived from a Chi-squared distribution with df = 2.
- reject: Logical. If TRUE, the null hypothesis is rejected at alpha.
- msg: Character string summarizing the test result, printed if quiet = FALSE.

References

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*, 48(4), 817–838.

See Also

lm, pchisq

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
eda_white_test(data, years)
```

---

fit_lmom_fast	*Helper Function for L-moments Parameter Estimation*

Description

A helper function used by fit_lmom_methods. This function does not validate parameters and is intended for internal use.

Usage

```
fit_lmom_fast(data, model)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`model`	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.

Value

A numeric vector of parameters:

- If `model` is `"GUM"`, `"NOR"`, or `"LNO"`, returns a vector of length 2.
- Otherwise, returns a vector of length 3.

References

Hosking, J.R.M. & Wallis, J.R., 1997. Regional frequency analysis: an approach based on L-Moments. Cambridge University Press, New York, USA.

See Also

lmom_sample, fit_lmom_kappa, fit_lmom_methods

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
fit_lmom_fast(data, "PE3")
```

---

fit_lmom_kappa   *L-Moments Parameter Estimation for the Kappa Distribution*

Description

This functions estimates the parameters of the four-parameter Kappa distribution using the method of L-moments. Since there is no known closed form solution for the parameters in terms of the L-moments, the parameters are computed numerically using Newton-Raphson iteration.

Usage

```
fit_lmom_kappa(data)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.

Details

First, the sample L-moments of the data are computed using the lmom_sample method. Then, the optim function is used to determine the parameters by minimizing the sumquad.tau3tau4 helper function. The implementation of this routine is based on the deprecated homtest package.

Value

A numeric vector of four parameters in the order location, scale, shape (1), shape (2).

References

Hosking, J.R.M. & Wallis, J.R., 1997. Regional frequency analysis: an approach based on L-Moments. Cambridge University Press, New York, USA.

See Also

lmom_sample, fit_lmom_fast, fit_lmom_methods

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
fit_lmom_kappa(data)
```

---

fit_lmom_methods *Parameter Estimation with L-Moments*

Description

Estimate the parameters of one of nine different distributions (GUM, NOR, LNO, GEV, GLO, GNO, PE3, LP3, and WEI) using the method of L-moments.

Usage

```
fit_lmom_gum(data)

fit_lmom_nor(data)

fit_lmom_lno(data)

fit_lmom_gev(data)

fit_lmom_glo(data)

fit_lmom_gno(data)

fit_lmom_pe3(data)

fit_lmom_lp3(data)

fit_lmom_wei(data)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.

Details

First, the sample L-moments of the data are computed using the lmom_sample method. Then formulas from Hosking (1997) are used to compute the parameters from the L-moments. Distributions GNO, PE3, and LP3 use a rational approximation to compute the parameters.

Value

A numeric vector of parameters:

- If model is "GUM", "NOR", or "LNO", returns a vector of length 2.
- Otherwise, returns a vector of length 3.

References

Hosking, J.R.M. & Wallis, J.R., 1997. Regional frequency analysis: an approach based on L-Moments. Cambridge University Press, New York, USA.

See Also

fit_lmom_fast, fit_lmom_kappa

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
fit_lmom_lp3(data)
```

---

fit_maximum_likelihood

Maximum Likelihood Parameter Estimation

Description

Estimates parameters of a probability distribution with an optional trend by maximizing the log-likelihood. Initial values are obtained through L-moment parameter estimation, and optimization is performed via nlminb with repeated perturbations if needed.

Usage

```
fit_maximum_likelihood(data, model, prior = NULL, years = NULL, trend = NULL)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
model	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
prior	Numeric vector of length 2. Specifies the Beta prior shape parameters (p, q) for the shape parameter κ. Only used when `model = "GEV"`.
years	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Details

1. Calls fit_lmom_fast on `data` to obtain initial parameter estimates.
2. Initializes trend parameters to zero if necessary.
3. For `WEI` models, sets the location parameter to zero to ensure support.
4. Defines an objective function using the likelihood functions loglik_fast or general_loglik_fast.
5. Runs nlminb with box constraints. Attempts optimization up to 100 times if a maximum cannot be found.

Value

A list containing the results of parameter estimation:

- `params`: Numeric vector of estimated parameters.
- `mll`: Maximum log-likelihood value.

Note

Although the more modern optim function is preferred over nlminb, we use nlminb because it supports non-finite values of the likelihood function.

See Also

loglik_fast, general_loglik_fast, fit_lmom_fast, nlminb

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
trend <- list(location = TRUE, scale = FALSE)
fit_maximum_likelihood(data, "GNO", NULL, years, trend)
```

---

general_loglik_fast

Generalized Log-Likelihood Helper Function

Description

A helper function used by general_loglik_gev. This function does not validate parameters and is intended for internal use.

Usage

```
general_loglik_fast(data, model, params, prior, years, trend)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`model`	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
`params`	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
`prior`	Numeric vector of length 2. Specifies the Beta prior shape parameters (p, q) for the shape parameter κ. Only used when `model = "GEV"`.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.

trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Value

Numeric scalar. The generalized log-likelihood value.

See Also

general_loglik_gev.

Examples

```
# Initialize data, params, prior, years, and trend
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(0, 1, 1, 0, 0)
prior <- c(5, 10)
years <- seq(from = 1901, to = 2000)
trend <- list(location = TRUE, scale = TRUE)

# Compute the generalized log-likelihood
general_loglik_fast(data, "GEV", params, prior, years, trend)
```

---

general_loglik_gev   *Generalized Log-Likelihood Functions for GEV Models*

Description

Computes the generalized log-likelihood for stationary and non-stationary variants of the Generalized Extreme Value (GEV) distribution with a Beta prior on the shape parameter.

Usage

```
general_loglik_gev(data, params, prior, years = NULL, trend = NULL)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
params	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
prior	Numeric vector of length 2. Specifies the Beta prior shape parameters (p, q) for the shape parameter κ. Only used when `model = "GEV"`.
years	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Details

The generalized log-likelihood is defined as sum of the log-likelihood of the specified model and the log-density of the Beta prior with parameters (p, q). The contribution of the prior is:

$$\log \pi(\kappa) = (p - 1) \log(0.5 - \kappa) + (q - 1) \log(0.5 + \kappa) - \log(\beta(p, q))$$

Value

Numeric scalar. The generalized log-likelihood value.

See Also

general_loglik_fast

Examples

```
# Initialize data, params, prior, years, and trend
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(0, 1, 1, 0)
prior <- c(5, 10)
years <- seq(from = 1901, to = 2000)
trend <- list(location = TRUE, scale = FALSE)

# Compute the generalized log-likelihood
general_loglik_gev(data, params, prior, years, trend)
```

---

lmom_fast   *Helper Function for L-moments Ratios*

Description

A helper function used by lmom_theoretical. This function does not validate parameters and is intended for internal use.

Usage

```
lmom_fast(model, params)
```

Arguments

model   Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.

params   Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.

Value

A numeric vector of length 4 containing:

- λ_1: L-mean
- λ_2: L-variance
- τ_3: L-skewness
- τ_4: L-kurtosis

Note

L-moment ratios for `NOR`/`LNO` and `PE3`/`LP3` are identical since it L-moments for the `LNO`/`LP3` distributions are compared with the sample L-moments of the logarithm of the data internally.

References

Hosking, J.R.M. & Wallis, J.R., 1997. Regional frequency analysis: an approach based on L-Moments. Cambridge University Press, New York, USA.

See Also

[lmom_theoretical](#)

Examples

```
lmom_fast("GLO", c(0, 1, 0))
```

   `lmom_sample`   *Sample L-moments*

Description

Computes the first four sample L-moments and L-moment ratios from a numeric vector of data. L-moments are linear combinations of order statistics that provide robust alternatives to conventional moments, with advantages in parameter estimation for heavy-tailed and skewed distributions.

Usage

```
lmom_sample(data)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly
              positive, finite, and non-missing.

Details

Given probability weighted moments $\beta_0, \beta_1, \beta_2, \beta_3$, the first four sample L-moments are:

- $l_1 = \beta_0$
- $l_2 = 2\beta_1 - \beta_0$
- $l_3 = 6\beta_2 - 6\beta_1 + \beta_0$
- $l_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0$

Then, the sample L-skewness is $t_3 = l_3/l_2$ and the sample L-kurtosis is $t_4 = l_4/l_2$.

Value

A numeric vector containing the first four L-moments and L-moment ratios:

- `l1`: L-mean
- `l2`: L-variance
- `t3`: L-skewness
- `t4`: L-kurtosis

Note

This function has no parameter validation because uncertainty_bootstrap makes many calls to it. If you are getting errors, ensure that `data` is a positive, numeric vector.

References

Hosking, J. R. M. (1990). L-moments: Analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society: Series B (Methodological)*, 52(1), 105–124.

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
lmom_sample(data)
```

---

lmom_theoretical   *Theoretical L-moments of Probability Distributions*

Description

Computes the first four L-moments and L-moment ratios of seven different probability distributions (`GUM`, `NOR`, `GEV`, `GLO`, `GNO`, `PE3`, and `WEI`) given the parameters of the distribution.

Usage

```
lmom_theoretical_gum(params)

lmom_theoretical_nor(params)

lmom_theoretical_gev(params)

lmom_theoretical_glo(params)

lmom_theoretical_gno(params)

lmom_theoretical_pe3(params)

lmom_theoretical_wei(params)
```

Arguments

params   Numeric vector of distribution parameters, in the order (location, scale, shape).
              The length must be between 2 and 5, depending on the specified `model` and
              `trend`.

Details

The distributions `GUM`, `NOR`, `GEV`, `GLO`, and `WEI` have closed-form solutions for the L-moments
and L-moment ratios in terms of the parameters. The distributions `GNO`, `PE3` use rational approxi-
mations of the L-moment ratios from Hosking (1997).

Value

A numeric vector of length 4 containing:

- λ_1: L-mean
- λ_2: L-variance
- τ_3: L-skewness
- τ_4: L-kurtosis

References

Hosking, J.R.M. & Wallis, J.R., 1997. Regional frequency analysis: an approach based on L-
Moments. Cambridge University Press, New York, USA.

See Also

lmom_fast

Examples

```
lmom_theoretical_gev(c(0, 1, 0))
```

`loglik_fast`	*Log-Likelihood Helper Function*

Description

A helper function used by loglik_methods. This function does not validate parameters and is intended for internal use.

Usage

```
loglik_fast(data, model, params, years, trend)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`model`	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
`params`	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
`trend`	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Value

Numeric scalar. The log-likelihood value.

See Also

loglik_methods

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(0, 1, 0)
years <- seq(from = 1901, to = 2000)
trend <- list(location = FALSE, scale = FALSE)
loglik_fast(data, "GEV", params, years, trend)
```

---

loglik_methods *Log-Likelihood Functions for Probability Models*

Description

Compute the log-likelihood value for stationary and non-stationary variants of nine different distributions: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.

Usage

```
loglik_gum(data, params, years = NULL, trend = NULL)

loglik_nor(data, params, years = NULL, trend = NULL)

loglik_lno(data, params, years = NULL, trend = NULL)

loglik_gev(data, params, years = NULL, trend = NULL)

loglik_glo(data, params, years = NULL, trend = NULL)

loglik_gno(data, params, years = NULL, trend = NULL)

loglik_pe3(data, params, years = NULL, trend = NULL)

loglik_lp3(data, params, years = NULL, trend = NULL)

loglik_wei(data, params, years = NULL, trend = NULL)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`params`	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
`trend`	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:
	• `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
	• `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Value

Numeric scalar. The log-likelihood value.

See Also

loglik_fast

Examples

```
# Initialize data, params, years, and trend
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(0, 1, 1, 0)
years <- seq(from = 1901, to = 2000)
trend <- list(location = TRUE, scale = FALSE)

# Compute the log-likelihood
loglik_gno(data, params, years, trend)
```

---

model_diagnostics   *Evaluate Goodness-of-Fit for Fitted Flood Models*

Description

Computes multiple performance metrics and diagnostic indicators to assess the quality of a fitted flood frequency model This includes residual statistics, information criteria, and coverage-based metrics using confidence intervals.

Usage

```
model_diagnostics(
  data,
  model,
  params,
  uncertainty,
  years = NULL,
  trend = NULL,
  alpha = 0.05,
  pp.formula = "Weibull"
)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
model	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
params	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
uncertainty	List; estimated reutrn levels and confidence intervals generated by uncertainty_bootstrap or uncertainty_rfpl.
years	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain: • `location`: Logical scalar. If `TRUE`, the location parameter has a trend.

- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

alpha   Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or
                     hypothesis tests. Default is 0.05.

pp.formula   Character (1); string specifying the plotting position formula. Must be one of
                     `"Weibull"`, `"Blom"`, `"Cunnane"`, `"Gringorten"`, or `"Hazen"`

Value

List containing model assessment metrics:

- `data`: The `data` argument.

- `estimates`: Quantile estimates for empirical return periods.

- `R2`: Coefficient of determination from linear regression of estimates vs. data.

- `RMSE`: Root mean squared error of quantile estimates.

- `bias`: Mean bias of quantile estimates.

- `AIC`: Akaike Information Criterion.

- `BIC`: Bayesian Information Criterion.

- `AIC_MLL`: Akaike Information Criterion, computed using MLE.

- `BIC_MLL`: Bayesian Information Criterion, computed using MLE.

- `AW`: Average width of the confidence interval(s).

- `POC`: Percent of observations covered by the confidence interval(s).

- `CWI`: Confidence width index, a metric that combines `AW` and `POC`.

See Also

uncertainty_bootstrap, uncertainty_rfpl, fit_maximum_likelihood

Examples

```
# Initialize example data and params
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(100, 10)

# Perform uncertainty analysis
uncertainty <- uncertainty_bootstrap(data, "NOR", "L-moments")

# Evaluate model diagnostics
model_diagnostics(data, "NOR", params, uncertainty)
```

| plot_bbmk_test | *Plot Block-Bootstrap Mann–Kendall Test Results* |

Description

Generates a histogram of bootstrapped Mann–Kendall S-statistics with vertical lines indicating the observed S-statistic and confidence bounds.

Usage

```
plot_bbmk_test(results, ...)
```

Arguments

results	List of BB-MK test results generated by eda_bbmk_test.
...	Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; A plot containing:

- A gray histogram of the distribution of bootstrapped S-statistics.
- A red vertical line at the lower and upper confidence bounds.
- A black vertical line at the observed S-statistic.

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
results <- eda_bbmk_test(data, samples = 1000L)
plot_bbmk_test(results)
```

| plot_lmom_diagram | *Plot L-Moment Ratio Diagram* |

Description

Generates a plot of L-moment ratios with the L-skewness on the x-axis and L-kurtosis on the y-axis. Plots the sample and log-sample L-moment ratios alongside the theoretical L-moment ratios for a set of candidate distributions. If the selection method is select_ldistance or select_lkurtosis, the plot will include a small inset around the L-moment ratios of the recommended distribution.

Usage

```
plot_lmom_diagram(results, ...)
```

Arguments

results	List of model selection results generated by select_ldistance, select_lkurtosis, or select_zstatistic.
...	Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; plot object containing the L-moment ratio diagram, with:

- L-moment ratio curves for each 3-parameter distribution.
- Points for the L-moment ratios of each 2-parameter distribution.
- Sample and log-sample L-moment ratio (t_3, t_4) points.

See Also

select_ldistance, select_lkurtosis, select_zstatistic

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
results <- select_ldistance(data)
plot_lmom_diagram(results)
```

| `plot_mks_test` | *Plot Mann–Kendall–Sneyers (MKS) Test Results* |

Description

Constructs a two-panel visualization of the MKS test. The upper panel plots the normalized progressive and regressive Mann–Kendall S-statistics over time, with dashed confidence bounds and potential trend-change points. The lower panel contains the annual maximum streamflow (AMS) data with the change points highlighted points along with an optional trend line.

Usage

```
plot_mks_test(results, show_trend = TRUE, ...)
```

Arguments

`results`	A list generated by eda_mks_test.
`show_trend`	If `TRUE` (default), draw a fitted line through the AMS data.
`...`	Optional named arguments: 'title', 'top_xlabel', 'top_ylabel', 'bottom_xlabel' and 'bottom_ylabel'.

Value

A `patchwork` object with two `ggplot2` panels stacked vertically.

See Also

eda_mks_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
results <- eda_mks_test(data, years)
plot_mks_test(results)
```

```
plot_model_diagnostics
```
Plot Model Assessment Results

Description

Creates a quantile–quantile plot comparing observed annual maximum streamflow (AMS) data to quantile estimates from a fitted parametric model. The 1:1 line is drawn in black and the model estimates are plotted as semi-transparent red points.

Usage

```
plot_model_diagnostics(results, ...)
```

Arguments

results   List; model assessment results generated by model_diagnostics.

...   Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; a plot containing:

- A black line representing a perfect model with no deviation from the data.

- Red points marking the estimated quantiles against the observed quantiles.

Examples

```
# Initialize example data and params
data <- rnorm(n = 100, mean = 100, sd = 10)
params <- c(100, 10)

# Perform uncertainty analysis
uncertainty <- uncertainty_bootstrap(data, "NOR", "L-moments")

# Evaluate model diagnostics
results <- model_diagnostics(data, "NOR", params, uncertainty)

# Generate a model assessment plot
plot_model_diagnostics(results)
```

---

plot_pettitt_test   *Plot Results from the Pettitt Change-Point Test*

Description

Creates a two-panel visualization of the Mann–Whitney–Pettitt test. The upper panel plots the Pettitt U_t statistic over time along with the significance threshold and potential change point. The lower panel displays the annual maximum streamflow (AMS) data with an optional trend line, estimates of the mean, and potential change point.

Usage

```
plot_pettitt_test(results, show_trend = TRUE, ...)
```

Arguments

results	A list generated by eda_pettitt_test.
show_trend	If TRUE (default), draw a fitted line through the AMS data.
...	Optional named arguments: 'title', 'top_xlabel', 'top_ylabel', 'bottom_xlabel' and 'bottom_ylabel'.

Value

A `patchwork` object with two `ggplot2` panels stacked vertically.

See Also

eda_pettitt_test

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
results <- eda_pettitt_test(data, years)
plot_pettitt_test(results)
```

---

plot_runs_test   *Plot Runs Test Results*

Description

Generates a residual plot of Sen's estimator applied to annual maximum streamflow (AMS) data with a horizontal dashed line at zero and an annotation of the Runs test .

Usage

```
plot_runs_test(results, type, ...)
```

Arguments

`results`	A list of runs test results generated by eda_runs_test.
`type`	A character scalar representing whether Sen's trend estimator was applied directly to the AMS data (`"mean"`) or to the moving-window variance of the data (`"variance"`). Must be either `"variance"` or `"mean"`.
`...`	Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; a plot containing:

- Black points for the residual at each year.
- A red dashed horizontal line at $y = 0$.
- A text annotation "Runs : X.XXX" in the plot area.

See Also

eda_runs_test

Examples

```
# Initialize data and years
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)

# Generate runs test plot
sens <- eda_sens_trend(data, years)
results <- eda_runs_test(sens)
plot_runs_test(results, "mean")
```

`plot_sens_trend`	*Plot Sen's Trend Estimator*

Description

Produces a scatter plot of the annual maximum streamflow (AMS) data or its variance against time, overlaid with Sen's trend estimator and an annotation of the fitted equation.

Usage

```
plot_sens_trend(results, type, show_trend = TRUE, ...)
```

Arguments

`results`	A list of Sen's trend estimates generated by eda_sens_trend.
`type`	A character scalar representing whether Sen's trend estimator was applied directly to the AMS data (`"mean"`) or to the moving-window variance of the data (`"variance"`). Must be either `"variance"` or `"mean"`.
`show_trend`	If `TRUE` (default), draw a fitted line through the AMS data.
`...`	Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; a plot containing:

- Black points for each year's AMS (or variance) value.
- Optional black line connecting the AMS data if `show_trend = TRUE`.
- Blue line representing Sen's trend estimator.
- A text annotation displaying the fitted equation $y = mx + b$.

See Also

eda_sens_trend

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
results <- eda_sens_trend(data, years)
plot_sens_trend(results, "mean")
```

---

plot_spearman_test *Plot Spearman's Rho Autocorrelation*

Description

Visualizes Spearman's rho autocorrelation coefficients with shaded points indicating statistical significance.

Usage

```
plot_spearman_test(results, ...)
```

Arguments

`results`	A list generated by eda_spearman_test.
`...`	Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Value

`ggplot`; a plot showing:

- Vertical segments from $y = 0$ up to each ρ value at its lag.
- Filled circles at each lag, filled black if serial correlation is detected.

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
results <- eda_spearman_test(data)
plot_spearman_test(results)
```

---

plot_uncertainty   *Plot Return Levels and Confidence Intervals*

Description

Constructs a time–series plot of estimated return levels along with their associated confidence intervals. The confidence bounds are shown as a shaded ribbon, and the point estimates are overlaid as a solid line. The return periods are displayed on a logarithmic scale.

Usage

```
plot_uncertainty(results, ...)
```

Arguments

results   A list of estimated return levels and confidence intervals generated by uncertainty_bootstrap or uncertainty_rfpl.

...   Optional named arguments: 'title', 'xlabel', and 'ylabel'.

Details

If the specified model is non-stationary, the slice argument is required and the return levels are reported as "Effective Return Periods".

Value

ggplot; a plot showing:

- A dashed black line for both the lower and upper confidence bounds.

- A semi-transparent gray ribbon between results$ci_lower and results$ci_upper.

- A solid blue line for the point estimates.

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
results <- uncertainty_bootstrap(data, "WEI", "L-moments")
plot_uncertainty(results)
```

---

quantile_fast	*Helper Function for Quantile Functions*

Description

A helper function used by quantile_methods.

Usage

```
quantile_fast(p, model, params, slice, trend)
```

Arguments

p   A numeric vector of probabilities. Must be between 0 and 1.

model   Character scalar. A three-character code indicating a distribution family. Must
             be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`,
             or `"WEI"`.

params   Numeric vector of distribution parameters, in the order (location, scale, shape).
             The length must be between 2 and 5, depending on the specified `model` and
             `trend`.

slice   Numeric scalar specifying the year at which to evaluate the quantiles or confi-
             dence intervals of a non-stationary probability distribution. The year does not
             have to be an element of the `years` argument. Note that if `trend$location`
             and `trend$scale` are both `FALSE`, this argument will have no effect the out-
             put of the function.

trend   Named list indicating which distribution parameters are modeled as non-stationary.
             Must contain:

             - `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
             - `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Value

A numeric vector of quantiles with the same length as p.

See Also

quantile_methods

Examples

```
# Initialize p, params, and trend
p <- runif(n = 10)
params <- c(0, 1, 1, 0)
trend <- list(location = FALSE, scale = TRUE)

# Compute the log-likelihood in the year 2000
quantile_fast(p, "GEV", params, 2000, trend)
```

---

quantile_methods *Quantile Functions for Probability Models*

Description

Compute the quantiles for stationary and non-stationary variants of nine different distributions: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.

Usage

```
quantile_gum(p, params, slice = NULL, trend = NULL)

quantile_nor(p, params, slice = NULL, trend = NULL)

quantile_lno(p, params, slice = NULL, trend = NULL)

quantile_gev(p, params, slice = NULL, trend = NULL)

quantile_glo(p, params, slice = NULL, trend = NULL)

quantile_gno(p, params, slice = NULL, trend = NULL)

quantile_pe3(p, params, slice = NULL, trend = NULL)

quantile_lp3(p, params, slice = NULL, trend = NULL)

quantile_wei(p, params, slice = NULL, trend = NULL)

quantile_kap(p, params, slice = NULL, trend = NULL)
```

Arguments

`p`	Numeric; a vector of probabilities between 0 and 1.
`params`	Numeric vector of distribution parameters, in the order (location, scale, shape). The length must be between 2 and 5, depending on the specified `model` and `trend`.
`slice`	Numeric scalar specifying the year at which to evaluate the quantiles or confidence intervals of a non-stationary probability distribution. The year does not have to be an element of the `years` argument. Note that if `trend$location` and `trend$scale` are both `FALSE`, this argument will have no effect the output of the function.
`trend`	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:
	• `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
	• `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

Value

A numeric vector of quantiles with the same length as `p`.

See Also

[quantile_fast](#)

Examples

```
# Initialize p and params
p <- runif(n = 10)
params <- c(0, 1, 0)

# Compute the quantiles
quantile_wei(p, params)
```

---

select_ldistance *L-Distance Method for Distribution Selection*

Description

Selects a distribution from a set of candidate distributions by minimizing the Euclidean distance between the theoretical L-moment ratios (τ_3, τ_4) and the sample L-moment ratios (t_3, t_4).

Usage

```
select_ldistance(data)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.

Details

For each candidate distribution, the method computes the Euclidean distance between sample L-moment ratios (τ_3, τ_4) and the closest point on the theoretical distribution's L-moment curve. For two-parameter distributions (Gumbel, Normal, Log-Normal), the theoretical L-moment ratios are compared directly with the sample L-moment ratios. The distribution with the minimum distance is selected. If a distribution is fit to log-transformed data (Log-Normal or Log-Pearson Type III), the L-moment ratios for the log-transformed sample are used instead.

Value

A list with the results of distribution selection:

- method: "L-distance".
- data: The data argument.
- metrics: A list of L-distance metrics for each candidate distribution.
- recommendation: The name of the distribution with the smallest L-distance.

See Also

[lmom_sample](#), [select_lkurtosis](#), [select_zstatistic](#), [plot_lmom_diagram](#)

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
select_ldistance(data)
```

---

select_lkurtosis   *L-Kurtosis Method for Distribution Selection*

Description

Selects a probability distribution by minimizing the absolute distance between the theoretical L-kurtosis (τ_4) and the sample L-kurtosis (t_4). For 3-parameter distributions, we use the shape parameter that best replicates the sample L-skewness (t_3) of the data.

Usage

```
select_lkurtosis(data)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.

Details

This method computes the distance between the sample and theoretical L-kurtosis values at a fixed L-skewness. For three parameter distributions, the shape parameter that best replicates the sample L-skewness is derived using optim.

Value

A list with the results of distribution selection:

- method: "L-kurtosis".
- data: The data argument.
- metrics: A list of L-kurtosis metrics for each distribution.
- recommendation: Name of the distribution with the smallest L-kurtosis metric

See Also

lmom_sample, select_ldistance, select_zstatistic, plot_lmom_diagram

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
select_lkurtosis(data)
```

---

select_zstatistic   *Z-Statistic Method for Distribution Selection*

Description

Selects the best-fit distribution by computing a bias-corrected Z-statistic for the sample L-kurtosis (τ_4) against the theoretical L-moments for a set of candidate distributions. The distribution with the smallest absolute Z-statistic is selected.

Usage

```
select_zstatistic(data, samples = 10000L)
```

Arguments

data   Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.

samples   Integer scalar. The number of bootstrap samples. Default is 10000.

Details

The method performs model selection using both raw and log-transformed data. The distributions which use the raw AMS data are GEV, GLO, PE3, GNO, and WEI. The LP3 distribution uses log-transformed data.

The Z-statistic is determined by fitting a four-parameter Kappa distribution to the raw and log-transformed data. Then, bootstrapped samples from this Kappa distribution The L-moments of these bootstrapped samples are used to estimate the Z-statistic for each distribution.

Value

A list with the results of distribution selection:

- method: "Z-selection".
- data: The data argument.
- metrics: List of computed Z-statistics for each candidate distribution.
- recommendation: Name of the distribution with the smallest Z-statistic.
- reg_params: Kappa distribution parameters for the AMS data.
- reg_bias_t4: Bias of the L-kurtosis from the AMS bootstrap.
- reg_std_t4: Standard deviation of the L-kurtosis from the AMS bootstrap.
- log_params: Kappa distribution parameters for the log-AMS data.
- log_bias_t4: Bias of the L-kurtosis from the log-AMS bootstrap.
- log_std_t4: Standard deviation of the L-kurtosis from the log-AMS bootstrap.

See Also

select_ldistance, select_lkurtosis, fit_lmom_kappa, quantile_fast, plot_lmom_diagram

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
select_zstatistic(data)
```

---

uncertainty_bootstrap

Sample Bootstrap Confidence Intervals for Flood Quantile Estimates

---

Description

Computes estimates and confidence intervals for return levels at return periods 2, 5, 10, 20, 50, and 100 years using the sample bootstrap method. This function supports a variety of probability models and parameter estimation methods.

Usage

```
uncertainty_bootstrap(
  data,
  model,
  method,
  prior = NULL,
  years = NULL,
  trend = NULL,
  slice = NULL,
  alpha = 0.05,
  samples = 10000L
)
```

Arguments

data	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
model	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
method	Character scalar specifying the estimation method. Must be `"L-moments"`, `"MLE"`, or `"GMLE"`.
prior	Numeric vector of length 2. Specifies the Beta prior shape parameters (p, q) for the shape parameter κ. Only used when `model = "GEV"`.
years	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
trend	Named list indicating which distribution parameters are modeled as non-stationary. Must contain:

- `location`: Logical scalar. If `TRUE`, the location parameter has a trend.
- `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.

slice   Numeric scalar specifying the year at which to evaluate the quantiles or confi-
               dence intervals of a non-stationary probability distribution. The year does not
               have to be an element of the `years` argument. Note that if `trend$location`
               and `trend$scale` are both `FALSE`, this argument will have no effect the out-
               put of the function.

alpha   Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or
               hypothesis tests. Default is 0.05.

samples   Integer scalar. The number of bootstrap samples. Default is 10000.

Details

The bootstrap procedure samples from the fitted distribution via inverse transform sampling. For
each bootstrapped sample, the parameters are re-estimated using the specified `method`. Then, the
bootstrapped parameters are used to compute a new set of bootstrapped quantiles. Confidence in-
tervals are obtained from the empirical non-exceedance probabilities of the bootstrapped quantiles.

Value

A list contianing the return levels and confidence intervals containing:

- `estimates`: Estimated quantiles for each return period.
- `ci_lower`: Lower bound of the confidence interval for each return period.
- `ci_upper`: Upper bound of the confidence interval for each return period.
- `t`: Vector of return periods; `c(2, 5, 10, 20, 50, 100)`.
- `slice`: The value of `slice` argument.
- `trend`: The value of `trend` argument.

See Also

fit_lmom_fast, fit_maximum_likelihood, lmom_sample, quantile_fast, plot_uncertainty

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
years <- seq(from = 1901, to = 2000)
uncertainty_bootstrap(data, "WEI", "L-moments")
```

---

uncertainty_rfpl   *Regula-Falsi Confidence Intervals for Flood Quantile Estimates*

Description

Calculates estimates and confidence intervals for return levels at standard return periods (2, 5, 10,
20, 50, and 100 years) using the profile likelihood and Regula-Falsi root-finding method.

Usage

```
uncertainty_rfpl(
  data,
  model,
  prior = NULL,
  years = NULL,
  trend = NULL,
  slice = NULL,
  alpha = 0.05,
  eps = 0.01
)
```

Arguments

`data`	Numeric vector of annual maximum streamflow (AMS) values. Must be strictly positive, finite, and non-missing.
`model`	Character scalar. A three-character code indicating a distribution family. Must be one of: `"GUM"`, `"NOR"`, `"LNO"`, `"GEV"`, `"GLO"`, `"GNO"`, `"PE3"`, `"LP3"`, or `"WEI"`.
`prior`	Numeric vector of length 2. Specifies the Beta prior shape parameters (p, q) for the shape parameter κ. Only used when `model = "GEV"`.
`years`	Numeric vector of observation years corresponding to `data`. Must be the same length as `data` and strictly increasing.
`trend`	Named list indicating which distribution parameters are modeled as non-stationary. Must contain: • `location`: Logical scalar. If `TRUE`, the location parameter has a trend. • `scale`: Logical scalar. If `TRUE`, the scale parameter has a trend.
`slice`	Numeric scalar specifying the year at which to evaluate the quantiles or confidence intervals of a non-stationary probability distribution. The year does not have to be an element of the `years` argument. Note that if `trend$location` and `trend$scale` are both `FALSE`, this argument will have no effect the output of the function.
`alpha`	Numeric scalar in $[0.01, 0.1]$. The significance level for confidence intervals or hypothesis tests. Default is 0.05.
`eps`	Numeric scalar. The log-likelihood tolerance for the Regula-Falsi convergence (default is 0.01).

Details

1. Fits the model using [fit_maximum_likelihood](#) to obtain parameter estimates and log-likelihood.

2. Defines an objective function $f(y_p, p)$ based on the chi-squared distribution.

3. Iteratively brackets the root by scaling initial guesses by 0.05 until $f(y_p, p)$ changes sign.

4. Uses the Regula Falsi method to solve $f(y_p, p) = 0$ for each return-period probability.

5. Returns lower and upper confidence bounds at significance level `alpha` given the return level estimates.

Value

A list contianing the return levels and confidence intervals containing:

- `estimates`: Estimated quantiles for each return period.
- `ci_lower`: Lower bound of the confidence interval for each return period.
- `ci_upper`: Upper bound of the confidence interval for each return period.
- `t`: Vector of return periods `c(2, 5, 10, 20, 50, 100)` in years.
- `slice`: The value of `slice` argument.
- `trend`: The value of `trend` argument.

Note

Although the more modern optim function is preferred over nlminb, we use nlminb because it supports non-finite values of the likelihood function.

See Also

quantile_fast, uncertainty_bootstrap, plot_uncertainty

Examples

```
data <- rnorm(n = 100, mean = 100, sd = 10)
uncertainty_rfpl(data, "GLO")
```

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