

Package ‘PRSim’

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Type Package

Title Stochastic Simulation of Streamflow Time Series using Phase Randomization

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Description Provides a simulation framework to simulate streamflow time series with similar main characteristics as observed data. These characteristics include the distribution of daily streamflow values and their temporal correlation as expressed by short- and long-range dependence. The approach is based on the randomization of the phases of the Fourier transform or the phases of the wavelet transform. The function `prsim()` is applicable to single site simulation and uses the Fourier transform. The function `prsim.wave()` extends the approach to multiple sites and is based on the complex wavelet transform. We further use the flexible four-parameter Kappa distribution, which allows for the extrapolation to yet unobserved low and high flows. Alternatively, the empirical or any other distribution can be used. A detailed description of the simulation approach for single sites and an application example can be found in <<https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-142/>>.

URL <https://git.math.uzh.ch/reinhard.furrer/PRSim-devel>

BugReports <https://git.math.uzh.ch/reinhard.furrer/PRSim-devel>

License GPL-3

Encoding UTF-8

LazyData true

Depends R (>= 3.5.0), homtest, goftest, wmtsa

Suggests lattice, ismev, evd, GB2

Imports stats

NeedsCompilation yes

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R topics documented:

PRSim-package	2
pRsim	4
pRsim.wave	6
runoff	9
runoff_multi_sites	10
simulations	11
simulations_multi_sites	12

Index	14
--------------	-----------

PRSim-package	<i>Stochastic Simulation of Streamflow Time Series using Phase Randomization</i>
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Description

Provides a simulation framework to simulate streamflow time series with similar main characteristics as observed data. These characteristics include the distribution of daily streamflow values and their temporal correlation as expressed by short- and long-range dependence. The approach is based on the randomization of the phases of the Fourier transform or the phases of the wavelet transform. The function `prsim()` is applicable to single site simulation and uses the Fourier transform. The function `prsim.wave()` extends the approach to multiple sites and is based on the complex wavelet transform. We further use the flexible four-parameter Kappa distribution, which allows for the extrapolation to yet unobserved low and high flows. Alternatively, the empirical or any other distribution can be used. A detailed description of the simulation approach for single sites and an application example can be found in <https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-142/>.

Details

The DESCRIPTION file:

```
Package:      PRSim
Type:         Package
Title:        Stochastic Simulation of Streamflow Time Series using Phase Randomization
Version:      1.2-1
Date:         2020-01-10
Authors@R:   c(person("Manuela", "Brunner", role = c("aut", "cre"), email = "manuela.i.brunner@gmail.com", comment = c
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Maintainer:  Manuela Brunner <manuela.i.brunner@gmail.com>
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Encoding:    UTF-8
LazyData:    true
```

Depends: R (>= 3.5.0), homtest, goftest, wmtsa
 Suggests: lattice, ismev, evd, GB2
 Imports: stats

Index of help topics:

PRSim-package	Stochastic Simulation of Streamflow Time Series using Phase Randomization
PRsim	Simulate for one station
PRsim.wave	Simulate for multiple stations
runoff	Sample runoff of a catchment
runoff_multi_sites	Sample runoff of four catchments with a similar discharge regime
simulations	Simulated runoff
simulations_multi_sites	Simulated runoff for four catchments

Contains two functions for the stochastic simulation of continuous discharge time series: `prsim` and `prsim.wave` both using phase randomization. `prsim` is based on the Fourier transform while `prsim.wave` uses the wavelet transform.

`prsim`: Simulation in the frequency domain is based on the randomization of the phases of the Fourier transform. We here combine phase randomization simulation with the flexible, four-parameter kappa distribution, which allows for the extrapolation to yet unobserved low and high flows. Alternative distributions or the empirical distribution can be used instead. The simulation approach consists of eight steps: (1) fitting of theoretical Kappa distribution, (2) normalization and deseasonalization, (3) Fourier transformation, (4) Fourier phases computation, (5) random phase generation, (6) inverse Fourier transformation, (7) back transformation, and (8) simulation.

`prsim.wave`: Simulation in the frequency domain based on the randomization of the phases of the continuous wavelet transform. We combine phase randomization with the flexible, four-parameter kappa distribution. Alternative theoretical distributions or the empirical distribution can be used instead. The simulation procedure consists of five steps: (1) Derivation of random phases from a white noise time series, (2) Fitting of kappa distribution, (3) Wavelet transform, (4) Inverse wavelet transform, and (5) Transformation to the kappa distribution (or the distribution of choice).

Author(s)

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Maintainer: Manuela Brunner <manuela.i.brunner@gmail.com>

References

Brunner, M. I., A. Bárdossy, and R. Furrer (2019). Technical note: Stochastic simulation of streamflow time series using phase randomization. *Hydrology and Earth System Sciences*, 23, 3175-3187, doi:10.5194/hess-23-3175-2019

Examples

```
## Not run:
demo("PRSim")
demo("PRSim-validate")
demo("PRSim_wave")
demo("PRSim_wave-validate")

## End(Not run)
```

pRsim

Simulate for one station

Description

Applies the algorithm to a single station

Usage

```
prsim(data, station_id="Qobs", number_sim=1, win_h_length=15,
      marginal=c("kappa","empirical"), n_par=4, marginalpar=TRUE,
      GoFtest=NULL, verbose=TRUE, suppWarn=FALSE, ...)
```

Arguments

data	data frame containing the time indications and runoff of at least one station. See ‘Details’.
station_id	identifies the station in case several runoffs are present in data. See ‘Details’.
number_sim	number of simulations to be carried out.
win_h_length	(half-)length of moving window size.
marginal	marginal distribution to be used for the backtransformation. Can be either "kappa", "empirical", or any type of CDF (see ‘Details’). "kappa" uses the four-parameter kappa distribution for backtransformation, "empirical" uses the empirical distribution. CDF allows for specifying any distribution ‘Examples’.
n_par	number of parameters of the marginal distribution used
GoFtest	If (non-null) a GoF test for daily data should be performed: "KS" performs a Kolmogorof-Smirnov test, and "AD" performs an Anderson-Darling test. see ‘Details’)
verbose	logical. Should progress be reported?
marginalpar	logical. Should the estimated parameters of the distribution used be returned?
suppWarn	logical. See ‘Details’.
...	any other argument passed to the sub-function specifying the cdf for fitting. See ‘Details’ and ‘Examples’.

Details

Time can be given with three columns named "YYYY", "MM", "DD", or as in POSIXct format YYYY-MM-DD. All leap days (Feb 29th) will be omitted from the analysis, but no missing observations are allowed.

Stations are identified by column name (default "Qobs"), or by column index.

The function `homtest::par.kappa` might issue quite a few warnings of type `In fn(par, ...) : value out of range in 'gammafn'`. The argument `suppWarn` allows to silence warnings for the specific function call via `suppressWarnings()`. Of course, a subsequent check via `warnings()` is recommended.

Alternative distributions can be specified by providing three functions: (1) a function fitting the parameters of a distributions and providing a vector of these parameters as output (`CDF_fit`), (2) a function simulating random numbers from this distribution (`rCDF`), and (3) a function specifying the distribution (`pCDF`). See 'Examples' for the generalized beta for the second kind and for the Generalized Extreme Values (GEV) distribution.

When using the kappa distribution, the AD test can for certain values of the parameter `h` not be performed.

Value

A list with elements

<code>simulation</code>	A data frame with time information, observations, deseasonalized observations and <code>number_sim</code> columns containing the simulated runoff.
<code>pars</code>	A matrix containing the estimated parameters of the marginal distribution (if <code>marginalpar</code>).
<code>p_val</code>	A vector containing the p-values of <code>ks.test</code> or <code>ad.test</code> applied to the daily detrended data (if <code>GoF.test</code> is not NULL)

Author(s)

Manuela Brunner

References

Brunner, M. I., A. Bárdossy, and R. Furrer (2019). Technical note: Stochastic simulation of stream-flow time series using phase randomization. *Hydrology and Earth System Sciences*, 23, 3175-3187, doi:10.5194/hess-23-3175-2019.

See Also

`ks.test`

Examples

```
data( runoff)
out <- prsim( runoff[ runoff$YYYY<1980, ], "Qobs", 1, suppWarn=TRUE)
# warnings() # as a follow-up to `suppWarn=TRUE`
```

```

## Specifying particular CDFs:
## (1) example with the Generalized Extreme Value (GEV) distribution
require("evd")
require("ismev")
rGEV <- function(n, theta) rgev(n, theta[1], theta[2], theta[3])
pGEV <- function(x, theta) pgev(x, theta[1], theta[2], theta[3])
GEV_fit <- function( xdat, ...) gev.fit( xdat, ...)$mle

## Not run: # The following call requires 5 seconds to execute
out <- prsim( runoff[ runoff$YYYY<1978, ], "Qobs", 1,
  marginal="GEV", n_par=3, verbose=FALSE, marginalpar=FALSE,
  show=FALSE) # Supress 'gev.fit' output.

## End(Not run)

## (2) example with generalized Beta distribution of the second kind
require( "GB2")
rGB2 <- function(n, theta) rgb2(n, theta[1], theta[2], theta[3], theta[4])
pGB2 <- function(x, theta) pgb2(x, theta[1], theta[2], theta[3], theta[4])
GB2_fit <- function( xdat, ...) ml.gb2( xdat, ...)$opt1$par

## Not run: # The following call requires half minute or so to execute. Some warnings are issued
out <- prsim( runoff[ runoff$YYYY<1987, ], "Qobs", 1, suppWarn=TRUE,
  marginal="GB2")

## End(Not run)

```

pRsim.wave

Simulate for multiple stations

Description

Applies the wavelet-based simulation algorithm to multiple sites (single site possible as well)

Usage

```

prsim.wave(data, station_id="Qobs", number_sim=1, win_h_length=15,
  marginal=c("kappa", "empirical"), n_par=4, n_wave=100, marginalpar=TRUE,
  GoFtest=NULL, verbose=TRUE, suppWarn=FALSE, ...)

```

Arguments

data	list of data frames. One list entry, i.e. data frame, corresponds to one station. Each data frame contains the time indications and runoff of one station. See ‘Details’.
station_id	identifies the station in case several time series are present in data. See ‘Details’.

number_sim	number of simulations to be carried out.
win_h_length	(half-)length of moving window size.
marginal	marginal distribution to be used for the backtransformation. Can be either "kappa", "empirical", or any type of CDF (see 'Details'). "kappa" uses the four-parameter kappa distribution for backtransformation, "empirical" uses the empirical distribution. CDF allows for specifying any distribution 'Examples'.
n_par	number of parameters of the marginal distribution used
GoFtest	If (non-null) a GoF test for daily data should be performed: "KS" performs a Kolmogorof-Smirnov test, and "AD" performs an Anderson-Darling test. see 'Details')
verbose	logical. Should progress be reported?
marginalpar	logical. Should the estimated parameters of the distribution used be returned?
n_wave	number of scales to be considered in the continuous wavelet transform.
suppWarn	logical. See 'Details'.
...	any other argument passed to the sub-function specifying the cdf for fitting. See 'Details' and 'Examples'.

Details

Time can be given with three columns named "YYYY", "MM", "DD", or as in POSIXct format YYYY-MM-DD. All leap days (Feb 29th) will be omitted from the analysis, but no missing observations are allowed.

Stations are identified by list index.

The function `homtest::par.kappa` might issue quite a few warnings of type `In fn(par, ...) : value out of range in 'gammafn'`. The argument `suppWarn` allows to silence warnings for the specific function call via `suppressWarnings()`. Of course, a subsequent check via `warnings()` is recommended.

Alternative distributions can be specified by providing three functions: (1) a function fitting the parameters of a distributions and providing a vector of these parameters as output (`CDF_fit`), (2) a function simulating random numbers from this distribution (`rCDF`), and (3) a function specifying the distribution (`pCDF`). See 'Examples' for the generalized beta for the second kind and for the Generalized Extreme Values (GEV) distribution.

When using the kappa distribution, the AD test can for certain values of the parameter `h` not be performed.

Value

A list with elements

simulation	A data frame with time information, observations, and <code>number_sim</code> columns containing the simulated runoff.
pars	A matrix containing the estimated parameters of the marginal distribution (if <code>marginalpar</code>).
p_val	A vector containing the p-values of <code>ks.test</code> or <code>ad.test</code> applied to the daily detrended data (if <code>GoFtest</code> is not NULL)

Author(s)

Manuela Brunner

References

Brunner and Gilleland to be submitted

See Also

ks.test

Examples

```

data(runoff_multi_sites)
## Not run: # The following call requires half minute or so to execute.
prsim.wave(runoff_multi_sites, "Qobs", 1, suppWarn=TRUE)

## End(Not run)
# warnings() # as a follow-up to `suppWarn=TRUE`

## Specifying particular CDFs:
## (1) example with the Generalized Extreme Value (GEV) distribution
require("evd")
require("ismev")
rGEV <- function(n, theta) rgev(n, theta[1], theta[2], theta[3])
pGEV <- function(x, theta) pgev(x, theta[1], theta[2], theta[3])
GEV_fit <- function(xdat, ...) gev.fit(xdat, ...)$mle

## Not run: # The following call requires 5 seconds to execute
prsim.wave(runoff_multi_sites, "Qobs", 1,
  marginal="GEV", n_par=3, verbose=FALSE, marginalpar=FALSE,
  show=FALSE)
# Supress 'gev.fit' output.

## End(Not run)

## (2) example with generalized Beta distribution of the second kind
require("GB2")
rGB2 <- function(n, theta) rgb2(n, theta[1], theta[2], theta[3], theta[4])
pGB2 <- function(x, theta) pgb2(x, theta[1], theta[2], theta[3], theta[4])
GB2_fit <- function(xdat, ...) ml.gb2(xdat, ...)$opt1$par

## Not run: # The following call requires half minute or so to execute.
Some warnings are issued
prsim.wave(runoff_multi_sites, "Qobs", 1, suppWarn=TRUE,
  marginal="GB2")

## End(Not run)

```

runoff	<i>Sample runoff of a catchment</i>
--------	-------------------------------------

Description

Artificial runoff data based on actual and simulated observations.

Usage

```
data("runoff")
```

Format

A data frame with 15695 observations of the following 4 variables.

YYYY a numeric vector, year

MM a numeric vector, month

DD a numeric vector, day

Qobs a numeric vector, synthetic observed runoff

Details

The data mimiks the runoff of the river Plessur at the gauging station Chur, Switzerland. The the flow regime of the river is melt dominated. More information is given in the reference below.

Source

The provided data is a weighted average of the acutually observed values and a particular simulated runoff. The actual discharge data can be ordered from <http://www.bafu.admin.ch/wasser/13462/13494/15076/index>.

References

Brunner, Bardossy, Furrer (2019) Technical note: Stochastic simulation of streamflow time series using phase randomization. Submitted.

Examples

```
data(runoff)
str(runoff)
runoff$timestamp <- paste(runoff$YYYY, runoff$MM, runoff$DD, sep=" ")
runoff$timestamp <- as.POSIXct(strptime(runoff$timestamp,
                                       format="%Y %m %d", tz="GMT"))
plot(runoff$timestamp[1:1000], runoff$Qobs[1:1000], type="l",
     xlab="Time [d]", ylab=expression(paste("Discharge [m^3,/s]")))
```

runoff_multi_sites *Sample runoff of four catchments with a similar discharge regime*

Description

Observed runoff data from four USGS sites.

Usage

```
data("runoff_multi_sites")
```

Format

A list of four data frames (one list per station) of the following 4 variables.

YYYY a numeric vector, year

MM a numeric vector, month

DD a numeric vector, day

Qobs a numeric vector, observed runoff

Details

The data contains runoff for four USGS gages: (i) Calawah River near Forks, WA (USGS 12043000), (ii) NF Stillaguamish River near Arlington, WA (USGS 12167000), (iii) Nehalem River near Foss, OR (USGS 14301000), and (iv) Steamboat Creek near Glide, OR (USGS 14316700).

Source

The actual discharge data were downloaded from <https://waterdata.usgs.gov/nwis>.

References

Brunner and Gilleland to be submitted.

Examples

```
data(runoff_multi_sites)
str(runoff_multi_sites)
runoff_multi_sites[[1]]$timestamp <- paste(runoff_multi_sites[[1]]$YYYY,
runoff_multi_sites[[1]]$MM, runoff_multi_sites[[1]]$DD, sep=" ")
runoff_multi_sites[[1]]$timestamp <-
as.POSIXct(strptime(runoff_multi_sites[[1]]$timestamp,format="%Y %m %d", tz="GMT"))
plot(runoff_multi_sites[[1]]$timestamp[1:1000], runoff_multi_sites[[1]]$Qobs[1:1000], type="l",
      xlab="Time [d]", ylab=expression(paste("Discharge [m3/s]")))
```

simulations	<i>Simulated runoff</i>
-------------	-------------------------

Description

The dataset is generated with the package own routines and represent 50 series of 18 years of runoff

Usage

```
data("simulations")
```

Format

A list of three elements, containing (i) a data frame with 6570 observations of the following 56 variables

YYYY a numeric vector, year

MM a numeric vector, month

DD a numeric vector, day

timestamp POSIXct vector of the daily runoff

deseasonalized deseasonalized time series

Qobs observed runoff

r1,...,r50 50 simulated runoff series

(ii) a data frame with the daily fitted kappa parameters and (iii) p-values of the daily ks. test.

Details

The data is included to illustrate the validation and visualization routines in `demo("PRSim-validate")`.

Source

The data has been generated with

```
set.seed(14); prsim(runoff[runoff$YYYY>1999,], number_sim=50, KStest=TRUE)
```

(default values for all other arguments).

References

Brunner, Bardossy, Furrer (2019) Technical note: Stochastic simulation of streamflow time series using phase randomization. Submitted.

Examples

```

data(simulations)
names(simulations)
sim <- simulations$simulation
dim(sim)
sim$day_id <- rep(seq(1:365), times=length(unique(sim$YYYY)))
mean_obs <- aggregate(sim$Qobs, by=list(sim$day_id), FUN=mean, simplify=FALSE)
plot(unlist(mean_obs[,2]),lty=1,lwd=1,col="black", ylab="Discharge [m3/s]",
      xlab="Time [d]", main="Mean hydrographs", ylim=c(0,22), type="l")

for(r in 7:(length(names(sim))-1)){
  mean_hydrograph <- aggregate(sim[,r], by=list(sim$day_id), FUN=mean, simplify=FALSE)
  lines(mean_hydrograph, lty=1, lwd=1, col="gray")
}
lines(mean_obs, lty=1, lwd=1, col="black")

```

simulations_multi_sites

Simulated runoff for four catchments

Description

The dataset is generated with the package own routines and represent 5 series of 38 years of runoff for four catchments

Usage

```
data("simulations_multi_sites")
```

Format

A list of four elements (one per catchment), containing a data frame each holding information about the observed time series and the stochastic simulations

YYYY a numeric vector, year

MM a numeric vector, month

DD a numeric vector, day

timestamp POSIXct vector of the daily runoff

Qobs observed runoff

r1,...,r5 5 simulated runoff series

Details

The data is included to illustrate the validation and visualization routines in `demo("PRSim_wave-validate")`.

Source

The data has been generated with

```
prsim.wave(data=runoff_multi_sites,number_sim=5,marginal="kappa",GoFtest=NULL,pars=NULL,p_val=NULL
(default values for all other arguments).
```

References

Brunner and Gilleland to be submitted

Examples

```
### greys
col_vect_obs <- c('#cccc', '#969696', '#636363', '#252525')
### oranges
col_vect_sim <- c('#f8be85', '#fd8d3c', '#e6550d', '#a63603')
data(simulations_multi_sites)
sim <- simulations_multi_sites
dim(sim[[1]])
### plot time series for multiple sites
par(mfrow=c(2,1),mar=c(3,3,2,1))
### determine ylim
ylim_max <- max(sim[[1]]$Qobs)*1.5
### observed
plot(sim[[1]]$Qobs[1:1000],
      ylab=expression(bold(
        paste("Specific discharge [mm/d]")),
      xlab="Time [d]",type="l",col=col_vect_obs[1],
      ylim=c(0,ylim_max),main='Observations')
for(l in 2:4){
  lines(sim[[1]]$Qobs[1:1000],col=col_vect_obs[l])
}
legend('topleft',legend=c('Station 1','Station 2',
  'Station 3','Station 4'),
  lty=1,col=col_vect_obs[1:4])
### simulated (one run)
plot(sim[[1]]$r1[1:1000],
      ylab=expression(bold(paste("Specific discharge [mm/d]")),
      xlab="Time [d]",type="l",col=col_vect_sim[1],
      ylim=c(0,ylim_max),
      main='Stochastic simulations')
for(l in 2:4){
  lines(sim[[1]]$r1[1:1000],col=col_vect_sim[l])
}
```

Index

*Topic **datasets**

- runoff, [9](#)
- runoff_multi_sites, [10](#)
- simulations, [11](#)
- simulations_multi_sites, [12](#)

*Topic **package**

- PRSim-package, [2](#)

*Topic **ts**

- pRsim, [4](#)
- pRsim.wave, [6](#)

PRSim (PRSim-package), [2](#)

PRsim (pRsim), [4](#)

pRsim, [4](#)

prsim (pRsim), [4](#)

PRSim-package, [2](#)

PRsim.wave (pRsim.wave), [6](#)

pRsim.wave, [6](#)

prsim.wave (pRsim.wave), [6](#)

prsim_wave (pRsim.wave), [6](#)

runoff, [9](#)

runoff multi sites
(runoff_multi_sites), [10](#)

runoff_multi_sites, [10](#)

simulations, [11](#)

simulations_multi_sites
(simulations_multi_sites), [12](#)

simulations_multi_sites, [12](#)