Package ‘qualypsoss’

August 31, 2022

Type Package

Date 2022-08-31

License GPL-3

Title Uncertainties of Climate Projections using Smoothing Splines

Version 1.1.1

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Imports foreach, doParallel, stats, utils, MASS, mvtnorm, graphics, grDevices,ggthemes,QUALYPSO

Description These functions use smoothing-splines for the assessment of single-member ensembles of climate projections.
- Cheng, C.-I. and P. L. Speckman (2012) <doi:10.1016/j.csda.2012.05.020>.

Depends R (>= 2.10)

Encoding UTF-8

RoxygenNote 7.1.2

NeedsCompilation no

Suggests knitr, rmarkdown

VignetteBuilder knitr

Repository CRAN

Date/Publication 2022-08-31 11:50:02 UTC

R topics documented:

`compute.change.variable` *Compute change variables*

Description

Compute change variables

Usage

```
compute.change.variable(climResponse, lOpt, lDim, iCpredContUnique, iCpredCont)
```

Arguments

`climResponse`	output from `extract.climate.response`
`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`iCpredContUnique`	index in `1:nP` indicating the reference continuous predictor for the computation of change variables.
`iCpredCont`	index in `1:nT` indicating the reference period (reference period) for the computation of change variables.

Value

list with the following fields:

- **phiStar.MCMC**: MCMC draws of climate change response
- **etaStar.MCMC**: MCMC draws of deviation from the climate change response

Author(s)

Guillaume Evin

`extract.climate.response` *Extract climate response for one time series z*

Description

Extract climate response for one time series z

Usage

```
extract.climate.response(
  ClimateProjections,
  predCont,
  predContUnique,
  nMCMC,
  lam,
  uniqueFit,
  spar = spar,
  listCR = NULL
)
```

Arguments

`ClimateProjections`	matrix of climate projections
`predCont`	matrix of continuous predictor corresponding to the climate projections
`predContUnique`	vector of predictors for which we need fitted climate reponses
`nMCMC`	number of MCMC samples
`lam`	fixed smoothing parameter lambda
`uniqueFit`	logical value indicating if only one fit is applied
`spar`	smoothing parameter `spar` in `smooth.spline`: must be greater than zero
`listCR`	list of objects for the extraction of the climate response

Value

list with the following fields:

- **phi.MCMC**: MCMC draws of climate response
- **eta.MCMC**: MCMC draws of deviation from the climate response
- **deltaIV.MCMC**: MCMC draws of deltaRV
- **listCR**: list of objects for faster computation on grids

Author(s)

Guillaume Evin

`formatQUALYPSSoutput` *formatQUALYPSSoutput*

Description

formatQUALYPSSoutput

Usage

```
formatQUALYPSSoutput(
  lOpt,
  lDim,
  lScen,
  ANOVA.step1,
  ANOVA.step2,
  ANOVA.step3,
  climResponse,
  change.variable
)
```

Arguments

`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`lScen`	list of scenario characteristics, output from `QUALYPSOSS.process.scenario`
`ANOVA.step1`	list provided by `QUALYPSOSS.ANOVA.step1`
`ANOVA.step2`	list provided by `QUALYPSOSS.ANOVA.step2`
`ANOVA.step3`	list provided by `QUALYPSOSS.ANOVA.step3`
`climResponse`	list containing phi, eta, provided by `extract.climate.response`
`change.variable`	list containing phiStar, etaStar, provided by `compute.change.variable`

Value

list with the following fields:

- **POINT**: list containing the mean estimate of different quantities: `RESIDUALVAR` (residual variability), `INTERNALVAR` (internal variability), `GRANDMEAN` (grand mean for all time steps), `MAINEFFECT` (list with one item per discrete predictor `i`, containing matrices `nT x nEffi`, where `nEffi` is the number of possible values for the discrete predictor `i`). `EFFECTVAR`, uncertainty related to the different main effect, `TOTVAR` Total variability, `DECOMPVAR`, decomposition of the total variability (percentages) for the different components, `CONTRIB_EACH_EFFECT`, contribution of each individual effects (percentages) to the corr. effect uncertainty.
- **BAYES**: list containing quantiles of different estimated quantities, listed in **POINT**.
- **MCMC**: MCMC draws for the different quantities.

Author(s)

Guillaume Evin

`get.det.AR1` *get.det.AR1 return the determinant of the matrix provided by* `get.matrix.AR1`

Description

get.det.AR1 return the determinant of the matrix provided by `get.matrix.AR1`

Usage

```
get.det.AR1(nP, rho, nMO)
```

Arguments

`nP`	number of continuous predictors (e.g. future times)
`rho`	AR(1) correlation parameter in (-1,1)
`nMO`	number of possible simulation chains (missing and non-missing)

Value

determinant of the AR1 matrix

Author(s)

Guillaume Evin

---

get.det.KMS *get.det.KMS return the determinant of the KMS matrix*

Description

get.det.KMS return the determinant of the KMS matrix

Usage

```
get.det.KMS(nP, rho)
```

Arguments

nP	number of continuous predictors (e.g. future times)
rho	AR(1) correlation parameter in (-1,1)

Value

determinant of the KMS matrix

Author(s)

Guillaume Evin

---

get.logdet.W *get.logdet.W Return the logarithm of the determinant of the matrix W*

Description

get.logdet.W Return the logarithm of the determinant of the matrix W

Usage

```
get.logdet.W(weight.hetero, nMO, nP, rho)
```

Arguments

`weight.hetero`	output of `get.vec.weight.hetero`
`nMO`	number of possible simulation chains (missing and non-missing)
`nP`	number of continuous predictors (e.g. future times)
`rho`	AR(1) correlation parameter in (-1,1)

Value

logarithm of the determinant of the matrix W

Author(s)

Guillaume Evin

`get.matrix.AR1` *get.matrix.AR1 return the matrix of AR(1) correlations corresponding to the entire ensemble*

Description

get.matrix.AR1 return the matrix of AR(1) correlations corresponding to the entire ensemble

Usage

```
get.matrix.AR1(nP, rho, nMO)
```

Arguments

`nP`	number of continuous predictors (e.g. future times)
`rho`	AR(1) correlation parameter in (-1,1)
`nMO`	number of possible simulation chains (missing and non-missing)

Value

C matrix n x n of AR(1) correlations where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

`get.matrix.AR1.inv` *get.matrix.AR1.inv return the inverse matrix of AR(1) correlations corresponding to the entire ensemble*

Description

get.matrix.AR1.inv return the inverse matrix of AR(1) correlations corresponding to the entire ensemble

Usage

```
get.matrix.AR1.inv(nP, rho, nMO)
```

Arguments

nP	number of continuous predictors (e.g. future times)
rho	AR(1) correlation parameter in (-1,1)
nMO	number of possible simulation chains (missing and non-missing)

Value

inverse matrix n x n of AR(1) correlations where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

`get.matrix.hetero` *get.matrix.hetero returns the matrix of weights for the computation of heteroscedastic errors corresponding to the entire ensemble*

Description

get.matrix.hetero returns the matrix of weights for the computation of heteroscedastic errors corresponding to the entire ensemble

Usage

```
get.matrix.hetero(weight.hetero, nMO)
```

Arguments

weight.hetero	output of get.vec.weight.hetero
nMO	number of possible simulation chains (missing and non-missing)

Value

V matrix n x n of weights where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

---

get.matrix.hetero.inv — *get.matrix.hetero.inv returns the inverse of the matrix of weights for the computation of heteroscedastic errors corresponding to the entire ensemble*

Description

get.matrix.hetero.inv returns the inverse of the matrix of weights for the computation of heteroscedastic errors corresponding to the entire ensemble

Usage

```
get.matrix.hetero.inv(weight.hetero, nMO)
```

Arguments

`weight.hetero`	output of `get.vec.weight.hetero`
`nMO`	number of possible simulation chains (missing and non-missing)

Value

inverse matrix n x n of weights where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

`get.matrix.KMS` *get.matrix.KMS Return the square Kac-Murdoch-Szego matrix for a rho correlation and n lines/colums*

Description

get.matrix.KMS Return the square Kac-Murdoch-Szego matrix for a rho correlation and n lines/colums

Usage

```
get.matrix.KMS(n, rho)
```

Arguments

n	nummber of lines/columns of the square matrix
rho	correlation parameter in [0,1]

Value

n x n Kac-Murdock-Szego matrix

Author(s)

Guillaume Evin

References

Kac, M., W. L. Murdock, and G. Szego. 1953. 'On the Eigen-Values of Certain Hermitian Forms' Journal of Rational Mechanics and Analysis 2: 767-800.

`get.matrix.KMSinv` *get.matrix.KMSinv return the inverse of the square Kac-Murdock-Szego matrix for a rho correlation and n lines/colums*

Description

get.matrix.KMSinv return the inverse of the square Kac-Murdock-Szego matrix for a rho correlation and n lines/colums

Usage

```
get.matrix.KMSinv(n, rho)
```

Arguments

n	nummber of lines/columns of the square matrix
rho	correlation parameter in (-1,1)

Value

n x n Kac-Murdock-Szego matrix

Author(s)

Guillaume Evin

References

Kac, M., W. L. Murdock, and G. Szego. 1953. 'On the Eigen-Values of Certain Hermitian Forms' Journal of Rational Mechanics and Analysis 2: 767-800.

`get.matrix.W` *get.matrix.W return the matrix of W = V x C x V for the treatment of heteroscedastic and AR(1) errors see Wang (2011) section 5.3 for further details*

Description

get.matrix.W return the matrix of W = V x C x V for the treatment of heteroscedastic and AR(1) errors see Wang (2011) section 5.3 for further details

Usage

```
get.matrix.W(weight.hetero, nMO, nP, rho)
```

Arguments

`weight.hetero`	output of `get.vec.weight.hetero`
`nMO`	number of possible simulation chains (missing and non-missing)
`nP`	number of continuous predictors (e.g. future times)
`rho`	AR(1) correlation parameter in (-1,1)

Value

matrix n x n where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

References

Wang, Y. 2011. 'Spline Smoothing with Heteroscedastic and/or Correlated Errors.' Smoothing Splines. Chapman and Hall/CRC. https://doi.org/10.1201/b10954-11.

`get.matrix.Winv` *get.matrix.Winv return the inverse matrix of W = V x C x V for the treatment of heteroscedastic and AR(1) errors see Wang (2011) section 5.3 for further details*

Description

get.matrix.Winv return the inverse matrix of W = V x C x V for the treatment of heteroscedastic and AR(1) errors see Wang (2011) section 5.3 for further details

Usage

```
get.matrix.Winv(weight.hetero, nMO, nP, rho)
```

Arguments

weight.hetero	output of get.vec.weight.hetero
nMO	number of possible simulation chains (missing and non-missing)
nP	number of continuous predictors (e.g. future times)
rho	AR(1) correlation parameter in (-1,1)

Value

inverse matrix n x n of weights where coden is the total number of predictions (all the predictions for all the possible simulation chains)

Author(s)

Guillaume Evin

References

Wang, Y. 2011. 'Spline Smoothing with Heteroscedastic and/or Correlated Errors' Smoothing Splines. Chapman and Hall/CRC. https://doi.org/10.1201/b10954-11.

`get.spectral.decomp` *get.spectral.decomp*

Description

compute different objects used for the application of Smoothing-Splines ANOVA (SS-ANOVA)

Usage

```
get.spectral.decomp(SIGMA)
```

Arguments

`SIGMA`	reproducing kernel

Value

list with the following fields:

- **Q**: Matrix of eigen vectors n x r,
- **D**: Vector of nonzero eigen values (size r),
- **r**: Number of nonzero eigen values (scalar).

Author(s)

Guillaume Evin

`get.target.logdensity.rho` *get.target.density.rho Return the log-density of the full conditional distribution for the parameter rho*

Description

get.target.density.rho Return the log-density of the full conditional distribution for the parameter rho

Usage

```
get.target.logdensity.rho(nFull, deltaRV, distSS, weight.hetero, nMO, nP, rho)
```

Arguments

`nFull`	nP x nMO
`deltaRV`	variance of the residual terms for the max value of the continuous predictor
`distSS`	sum of square distances between the climate change responses and the ANOVA model
`weight.hetero`	output of `get.vec.weight.hetero`
`nMO`	number of possible simulation chains (missing and non-missing)
`nP`	number of continuous predictors (e.g. future times)
`rho`	AR(1) correlation parameter in (-1,1)

Value

log-density of the full conditional distribution

Author(s)

Guillaume Evin

`get.vec.weight.hetero` *get.vec.weight.hetero returns the vector of weights for the computation of heteroscedastic errors corresponding to one simulation chain*

Description

get.vec.weight.hetero returns the vector of weights for the computation of heteroscedastic errors corresponding to one simulation chain

Usage

```
get.vec.weight.hetero(nP, type.weight.hetero)
```

Arguments

`nP` length of the continuous predictor for which we want to obtain the prediction (e.g. time) we suppose that continuous predictor is regularly spaced (e.g. 1990,2000,2010,...)

`type.weight.hetero`
"constant" (homoscedastic) or "linear" (heteroscedastic)

Value

vector of square roots of weights of the same length than `predContUnique`

Author(s)

Guillaume Evin

`get.yMCMC` *get.yMCMC*

Description

Get matrix `nMCMC` x `nFull` of climate responses where `nMCMC` is the number of MCMC draws and `nFull` is the number of possible combinations of predictors (discrete AND continuous),

Usage

```
get.yMCMC(lOpt, lDim, lScen, change.variable)
```

Arguments

`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`lScen`	list of scenario characteristics, output from `QUALYPSOSS.process.scenario`
`change.variable`	output from `compute.change.variable` containing MCMC draws of climate change response

Value

strongyMCMC: matrix `nMCMC` x `nFull` of climate responses

Author(s)

Guillaume Evin

`plotQUALYPSOSSClimateChangeResponse`
plotQUALYPSOSSClimateChangeResponse

Description

Plot climate change responses.

Usage

```
plotQUALYPSOSSClimateChangeResponse(
  QUALYPSOSSOUT,
  lim = NULL,
  col = NULL,
  xlab = "Years",
  ylab = expression(phi^{     star }),
  ...
)
```

Arguments

`QUALYPSOSSOUT`	output from `QUALYPSOSS`
`lim`	y-axis limits (default is NULL)
`col`	color for the lines
`xlab`	x-axis label
`ylab`	y-axis label
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

plotQUALYPSOSSClimateResponse
plotQUALYPSOSSClimateResponse

Description

Plot climate responses.

Usage

```
plotQUALYPSOSSClimateResponse(
  QUALYPSOSSOUT,
  lim = NULL,
  col = NULL,
  xlab = "Years",
  ylab = expression(phi),
  ...
)
```

Arguments

QUALYPSOSSOUT	output from QUALYPSOSS
lim	y-axis limits (default is NULL)
col	color for the lines
xlab	x-axis label
ylab	y-axis label
...	additional arguments to be passed to plot

Author(s)

Guillaume Evin

plotQUALYPSOSSeffect *plotQUALYPSOSSeffect*

Description

Plot prediction of ANOVA effects for one main effect. By default, we plot we plot the credible intervals corresponding to a probability 0.95.

Usage

```
plotQUALYPSOSSeffect(
  QUALYPSOSSOUT,
  iEff,
  CIlevel = c(0.025, 0.975),
  lim = NULL,
  col = 1:20,
  xlab = "Continuous predictor",
  ylab = "Effect",
  addLegend = TRUE,
  ...
)
```

Arguments

`QUALYPSOSSOUT`	output from `QUALYPSOSS`
`iEff`	index of the main effect to be plotted in `QUALYPSOSSOUT$listScenario$predDiscreteUnique`
`CIlevel`	probabilities for the credible intervals, default is equal to `c(0.025,0.975)`
`lim`	y-axis limits (default is NULL)
`col`	colors for each effect
`xlab`	x-axis label
`ylab`	y-axis label
`addLegend`	if TRUE, a legend is added
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

`plotQUALYPSOSSgrandmean`

plotQUALYPSOSSgrandmean

Description

Plot prediction of grand mean ensemble. By default, we plot the credible interval corresponding to a probability 0.95.

Usage

```
plotQUALYPSOSSgrandmean(
  QUALYPSOSSOUT,
  CIlevel = c(0.025, 0.975),
  lim = NULL,
  col = "black",
  xlab = "Continuous predictor",
  ylab = "Grand mean",
  addLegend = T,
  ...
)
```

Arguments

`QUALYPSOSSOUT`	output from `QUALYPSOSS`
`CIlevel`	probabilities for the credible intervals, default is equal to `c(0.025,0.975)`
`lim`	y-axis limits (default is NULL)
`col`	color for the overall mean and the credible interval
`xlab`	x-axis label
`ylab`	y-axis label
`addLegend`	if TRUE, a legend is added
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

`plotQUALYPSOSSTotalVarianceDecomposition` *plotQUALYPSOSSTotalVarianceDecomposition*

Description

Plot fraction of total variance explained by each source of uncertainty.

Usage

```
plotQUALYPSOSSTotalVarianceDecomposition(
  QUALYPSOSSOUT,
  col = c("orange", "yellow", "cadetblue1", "blue1", "darkgreen", "darkgoldenrod4",
    "darkorchid1"),
  xlab = "Continuous predictor",
  ylab = "% Total Variance",
  addLegend = TRUE,
  ...
)
```

Arguments

`QUALYPSOSSOUT`	output from `QUALYPSOSS`
`col`	colors for each source of uncertainty, the first two colors corresponding to internal variability and residual variability, respectively
`xlab`	x-axis label
`ylab`	y-axis label
`addLegend`	if TRUE, a legend is added
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

`predGlobTemp` *Annual average of global temperatures simulated by different CMIP5 GCMs at the planetary scale for the period 1971-2099*

Description

Annual average of global temperatures simulated by different CMIP5 GCMs at the planetary scale for the period 1971-2099

Usage

```
data(predGlobTemp)
```

Format

matrix 129 years x 20 scenarios

Author(s)

Guillaume Evin `<guillaume.evin@inrae.fr>`

`predGlobTempUnique` *Equally spaced vector of simulated global temperatures over the period 1971-2099 for the RCP8.5*

Description

Equally spaced vector of simulated global temperatures over the period 1971-2099 for the RCP8.5

Usage

```
data(predGlobTempUnique)
```

Format

vector of length 13

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`predTime` *Years 1971-2099 repeated for the 20 scenarios*

Description

Years 1971-2099 repeated for the 20 scenarios

Usage

```
data(predTime)
```

Format

matrix 129 years x 20 scenarios

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`predTimeUnique` *Equally spaced vector of years over the period 1971-2099*

Description

Equally spaced vector of years over the period 1971-2099

Usage

```
data(predTimeUnique)
```

Format

vector of length 13

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`QUALYPSOSS` *QUALYPSOSS*

Description

QUALYPSOSS

Usage

```
QUALYPSOSS(
  ClimateProjections,
  scenAvail,
  vecYears = NULL,
  predCont = NULL,
  predContUnique = NULL,
  iCpredCont = NULL,
  iCpredContUnique = NULL,
  listOption = NULL,
  RK = NULL
)
```

Arguments

ClimateProjections
: matrix nT x nS of climate projections where nT is the number of values for the continuous predictor (years, global temperature) and nS the number of scenarios.

scenAvail
: matrix of scenario characteristics nS x nK where nK is the number of discrete predictors.

vecYears
: (optional) vector of years of length nT (by default, a vector 1:nT).

predCont
: (optional) matrix nT x nS of continuous predictors.

predContUnique
: (optional) vector of length nP corresponding to the continuous predictor for which we want to obtain the prediction.

iCpredCont
: (optional) index in 1:nT indicating the reference period (reference period) for the computation of change variables.

iCpredContUnique
: (optional) index in 1:nP indicating the reference continuous predictor for the computation of change variables.

listOption
: (optional) list of options

- **spar**: if uniqueFit is true, smoothing parameter passed to the function smooth.spline.
- **lambdaClimateResponse**: smoothing parameter > 0 for the extraction of the climate response.
- **lambdaHyperParANOVA**: hyperparameter b for the λ parameter related to each predictor g.
- **typeChangeVariable**: type of change variable: "abs" (absolute, value by default) or "rel" (relative).
- **nBurn**: number of burn-in samples (default: 1000). If nBurn is too small, the convergence of MCMC chains might not be obtained.
- **nKeep**: number of kept samples (default: 2000). If nKeep is too small, MCMC samples might not be represent correctly the posterior distributions of inferred parameters.
- **quantileCompress**: vector of probabilities (in [0,1]) for which we compute the quantiles from the posterior distributions quantileCompress = c(0.005,0.025,0.05,0.5,0.95,0.975,0.995) by default.
- **uniqueFit**: logical, if FALSE (default), climate responses are fitted using Bayesian smoothing splines, otherwise,if TRUE, a unique cubic smoothing spline is fitted for each run, using the function smooth.spline.
- **returnMCMC**: logical, if TRUE, the list MCMC contains MCMC chains.
- **returnOnlyCR**: logical, if TRUE (default), only Climate Responses are fitted and returned.
- **type.temporal.dep**: "iid" for independent errors or "AR1" (default) for autocorrelated errors.
- **type.hetero**: "constant" for homoscedastic errors or "linear" (default) for heteroscedastic errors.

RK
: Reproducing kernels: list

Value

list with the following fields:

- **POINT**: list containing the mean estimate of different quantities: `RESIDUALVAR` (residual variability), `INTERNALVAR` (internal variability), `GRANDMEAN` (grand mean for all time steps), `MAINEFFECT` (list with one item per discrete predictor `i`, containing matrices `nT` x `nEffi`, where `nEffi` is the number of possible values for the discrete predictor `i`). `EFFECTVAR`, uncertainty related to the different main effect, `TOTVAR` Total variability, `DECOMPVAR`, decomposition of the total variability (percentages) for the different components, `CONTRIB_EACH_EFFECT`, contribution of each individual effects (percentages) to the corr. effect uncertainty.
- **BAYES**: list containing quantiles of different estimated quantities, listed in **POINT**.
- **MCMC**: list containing the MCMC chains (not returned by default).
- **climateResponse**: list containing different objects related to the extraction of the climate response. phiStar (ϕ^*) is an array `nQ` x `nS` x `nP` containing climate change responses, where `nQ` is the number of returned quantiles, `nS` is the number of scenarios and `nP` is the length of `predContUnique` (e.g. number of future years). Similarly, etaStar (η^*) contains the deviation from the climate change response. phi (ϕ) contains the climate responses and eta (η) contains the deviations from the climate responses.
- **listCR**: list containing objects created during the extraction of the climate responses
- **ClimateProjections**: argument of the call to the function, for records.
- **predCont**: (optional) argument of the call to the function, for records.
- **predContUnique**: (optional) argument of the call to the function, for records.
- **predDiscreteUnique**: list of possible values taken by the discrete predictors given in `scenAvail`.
- **listOption**: list of options
- **listScenario**: list of scenario characteristics (obtained from `QUALYPSOSS.process.scenario`)
- **RK**: list containing the reproducing kernels

Author(s)

Guillaume Evin

Examples

```
##############################################################################
# SYNTHETIC SCENARIOS
##############################################################################
# create nS=3 fictive climate scenarios with 2 GCMs and 2 RCMs, for a period of nY=20 years
n=20
t=1:n/n

# GCM effects (sums to 0 for each t)
effGCM1 = t*2
effGCM2 = t*-2

# RCM effects (sums to 0 for each t)
effRCM1 = t*1
```

```
effRCM2 = t*-1

# These climate scenarios are a sum of effects and a random gaussian noise
scenGCM1RCM1 = effGCM1 + effRCM1 + rnorm(n=n,sd=0.5)
scenGCM1RCM2 = effGCM1 + effRCM2 + rnorm(n=n,sd=0.5)
scenGCM2RCM1 = effGCM2 + effRCM1 + rnorm(n=n,sd=0.5)
ClimateProjections = cbind(scenGCM1RCM1,scenGCM1RCM2,scenGCM2RCM1)

# Here, scenAvail indicates that the first scenario is obtained with the combination of the
# GCM "GCM1" and RCM "RCM1", the second scenario is obtained with the combination of
# the GCM "GCM1" and RCM "RCM2" and the third scenario is obtained with the combination
# of the GCM "GCM2" and RCM "RCM1".
scenAvail = data.frame(GCM=c('GCM1','GCM1','GCM2'),RCM=c('RCM1','RCM2','RCM1'))

listOption = list(nBurn=20,nKeep=30,type.temporal.dep="iid",type.hetero="constant")
QUALYPSOSSOUT = QUALYPSOSS(ClimateProjections=ClimateProjections,scenAvail=scenAvail,
listOption=listOption)

# QUALYPSOSSOUT output contains many different information about climate projections uncertainties,
# which can be plotted using the following functions.

# plotQUALYPSOSSClimateResponse draws the climate responses, for all simulation chains,
# in comparison to the raw climate responses.
plotQUALYPSOSSClimateResponse(QUALYPSOSSOUT)

# plotQUALYPSOSSClimateChangeResponse draws the climate change responses, for all simulation chains.
plotQUALYPSOSSClimateChangeResponse(QUALYPSOSSOUT)

# plotQUALYPSOSSeffect draws the estimated effects, for a discrete predictor specified by iEff,
# as a function of the continuous predictor.
plotQUALYPSOSSeffect(QUALYPSOSSOUT, iEff = 1)
plotQUALYPSOSSeffect(QUALYPSOSSOUT, iEff = 2)

# plotQUALYPSOSSgrandmean draws the estimated grand mean, as a function of the continuous predictor.
plotQUALYPSOSSgrandmean(QUALYPSOSSOUT)

# plotQUALYPSOSSTotalVarianceDecomposition draws the decomposition of the total variance responses,
# as a function of the continuous predictor.
plotQUALYPSOSSTotalVarianceDecomposition(QUALYPSOSSOUT)
```

QUALYPSOSS.ANOVA.step1 *QUALYPSOSS.ANOVA.step1*

Description

SSANOVA decomposition of the ensemble of climate change responses using a Bayesian approach. The different fields of the returned list contain n samples from the posterior distributions of the different inferred quantities. In this first step, the residual errors are assumed iid

Usage

```
QUALYPSOSS.ANOVA.step1(lOpt, lDim, yMCMC, RK)
```

Arguments

`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`yMCMC`	array `nMCMC` x `nFull` of climate change responses
`RK`	large object containing the reproducing kernels, returned by `QUALYPSOSS.get.RK`

Value

list containing diverse information aboutwith the following fields:

- **g.MCMC**: Smooth effects `g`: array `n` x `nFull` x `K` where `nFull` is the number of possible combinations of predictors (discrete AND continuous),
- **nu.MCMC**: Smooth effects `nu`, a list with matrices of eigen vectors
- **lambda.MCMC**: Smoothing parameters: matrix `n` x `K`,
- **deltaRV.MCMC**: Residual variance: vector of length `n`,
- **g.hat**: Smooth effects estimates: matrix `nFull` x `K` where
- **nu.hat**: Smooth effects estimates: a list with estimates of eigen vectors,
- **lambda.hat**: Smoothing parameters estimates: vector of length `K`,
- **deltaRV.hat**: Residual variance estimate.
- **logLK**: vector of log-likelihood values of the draws
- **logPost**: vector of log-posterior values of the draws
- **Schwarz**: Schwarz criteria
- **BIC**: BIC criteria

Author(s)

Guillaume Evin

`QUALYPSOSS.ANOVA.step2`

QUALYPSOSS.ANOVA.step2

Description

SSANOVA decomposition of the ensemble of climate change responses using a Bayesian approach. In this second step, we infer deltaRV (variance of the residual errors) and phi (autocorrelation lag-1) considering hetero-autocorrelated residual errors, conditionally to smooth effects inferred in `QUALYPSOSS.ANOVA.step1`

Usage

```
QUALYPSOSS.ANOVA.step2(lOpt, lDim, yMCMC, gSum.step1, deltaRV.step1)
```

Arguments

`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`yMCMC`	array `nMCMC` x `nFull` of climate change responses
`gSum.step1`	sum of smooth effect estimates provided by `QUALYPSOSS.ANOVA.step1`
`deltaRV.step1`	residual variance estimate provided by `QUALYPSOSS.ANOVA.step1`

Value

list containing diverse information aboutwith the following fields:

- **rho.MCMC**: autocorrelation parameter of the AR(1) process: vector of length `n`
- **deltaRV.MCMC**: Residual variance: vector of length `n`,
- **rho.hat**: autocorrelation parameter estimate of the AR(1) process,
- **deltaRV.hat**: Residual variance estimate.

Author(s)

Guillaume Evin

`QUALYPSOSS.ANOVA.step3` *QUALYPSOSS.ANOVA.step3*

Description

SSANOVA decomposition of the ensemble of climate change responses using a Bayesian approach. In this second step, we infer deltaRV (variance of the residual errors) and phi (autocorrelation lag-1) considering hetero-autocorrelated residual errors, conditionally to smooth effects inferred in `QUALYPSOSS.ANOVA.step1`

Usage

```
QUALYPSOSS.ANOVA.step3(
  lOpt,
  lDim,
  yMCMC,
  RK,
  g.step1,
  lambda.step1,
  rho.step2,
  deltaRV.step2
)
```

Arguments

`lOpt`	list of options, returned by `QUALYPSOSS.check.option`
`lDim`	list of dimensions
`yMCMC`	array `nMCMC` x `nFull` of climate change responses
`RK`	large object containing the reproducing kernels, returned by `QUALYPSOSS.get.RK`
`g.step1`	smooth effect estimates provided by `QUALYPSOSS.ANOVA.step1`
`lambda.step1`	smooth parameter estimates provided by `QUALYPSOSS.ANOVA.step1`
`rho.step2`	lag-1 autocorrelation estimate provided by `QUALYPSOSS.ANOVA.step2`
`deltaRV.step2`	residual variance estimate provided by `QUALYPSOSS.ANOVA.step2`

Value

list containing diverse information aboutwith the following fields:

- **g.MCMC**: Smooth effects `g`: array `n` x `nFull` x `K` where `nFull` is the number of possible combinations of predictors (discrete AND continuous),
- **g.hat**: Smooth effects estimates: matrix `nFull` x `K` where `nFull` is the number of possible combinations of predictors (discrete AND continuous),
- **Schwarz**: Schwarz criteria
- **BIC**: BIC criteria

Author(s)

Guillaume Evin

`QUALYPSOSS.check.option`

QUALYPSOSS.check.option

Description

Check if input options provided in `QUALYPSOSS` are valid and assigned default values if missing.

Usage

```
QUALYPSOSS.check.option(listOption)
```

Arguments

`listOption`	list of options

Value

List containing the complete set of options.

Author(s)

Guillaume Evin

QUALYPSOSS.get.RK *QUALYPSOSS.get.RK*

Description

Get reproducing kernel for each discrete predictor

Usage

```
QUALYPSOSS.get.RK(X, nK)
```

Arguments

`X`	matrix of predictors
`nK`	number of discrete predictors

Value

strongRK: list containing the reproducing kernels, obtained using spectral decomposition

Author(s)

Guillaume Evin

QUALYPSOSS.process.scenario *QUALYPSOSS.process.scenario*

Description

compute different objects used for the application of Smoothing-Splines ANOVA (SS-ANOVA), these objects being processed outputs of the scenario characteristics

Usage

```
QUALYPSOSS.process.scenario(scenAvail, predContUnique)
```

Arguments

`scenAvail`	matrix of scenario characteristics `nS` x `nK`.
`predContUnique`	(optional) unique values of continuous predictors.

Value

list containing diverse information aboutwith the following fields:

- **scenAvail**: Record first argument of the function,
- **predContUnique**: Record second argument of the function,
- **XFull**: data.frame with all possible combinations of predictors (continuous AND discrete),
- **nFull**: number of rows of `XFull`,
- **nK**: Number of columns of `ScenAvail` (i.e. number of discrete predictors),
- **predDiscreteUnique**: List containing possible values for each discrete predictor.

Author(s)

Guillaume Evin

`reproducing.kernel` *reproducing.kernel*

Description

see par 2.3 in Cheng and Speckman

Usage

```
reproducing.kernel(x, y = NULL, type, typeRK = "Cheng")
```

Arguments

`x`	vector of predictors (continuous or discrete)
`y`	vector of predictors (continuous or discrete)
`type`	'continuous' or 'discrete'
`typeRK`	type of reproducing kernels: c('Cheng','Gu','Gaussian')

Value

matrix n x n

Author(s)

Guillaume Evin

`scenAvail` *scenAvail gives the GCM and RCM which have been used for the 20 climate projections*

Description

scenAvail gives the GCM and RCM which have been used for the 20 climate projections

Usage

```
data(scenAvail)
```

Format

data.frame with 20 rows and two columns: GCM and RCM

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`vecYears` *vecYears gives the years corr. to Y, i.e. from 1971 to 2099*

Description

vecYears gives the years corr. to Y, i.e. from 1971 to 2099

Usage

```
data(vecYears)
```

Format

vectors of length 129

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

Y *climate projections of mean winter (DJF) temperature over the SREX region CEU simulated by 20 combinations of CMIP5 GCMs and RCMs for the period 1971-2099*

Description

climate projections of mean winter (DJF) temperature over the SREX region CEU simulated by 20 combinations of CMIP5 GCMs and RCMs for the period 1971-2099

Usage

```
data(Y)
```

Format

matrix 129 years x 20 scenarios

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

References

Seneviratne, S. I. et al. Changes in Climate Extremes and their Impacts on the Natural Physical Environment, in: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change, edited by: Field, C., Barros, V., Stocker, T., and Dahe, Q., Cambridge University Press, Cambridge, 109-230, https://doi.org/10.1017/CBO9781139177245.006, 2012

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