Package 'qualypsoss'

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Title Uncertainties of Climate Projections using Smoothing Splines

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Imports foreach, doParallel, methods, stats, utils, MASS, mvtnorm, graphics, grDevices

Description These functions use smoothing-splines, data augmentation and Bayesian techniques for the assessment of single-member and incomplete ensembles of climate projections.
- Cheng, C.-I. and P. L. Speckman (2012) <doi:10.1016/j.csda.2012.05.020>.
- Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. (2019) <doi:10.1175/JCLI-D-18-0606.1>.

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R topics documented:

`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, parSmooth = 1, 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
`parSmooth`	smoothing parameter `spar` in `smooth.spline`: varies in [0,1]
`listCR`	list of objects for the extraction of the climate response

Value

list with the following fields:

- **phi**: MCMC draws of climate response
- **eta**: MCMC draws of deviation from the climate response
- **sigma2**: MCMC draws of sigma2
- **beta**: MCMC draws of beta

Author(s)

Guillaume Evin

`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

`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, includeMean = FALSE,
  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
includeMean	if TRUE, the grand mean is added to the main effect in the plot
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

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plotQUALYPSOSSTotalVarianceByScenario

plotQUALYPSOSSTotalVarianceByScenario

Description

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

Usage

```
plotQUALYPSOSSTotalVarianceByScenario(QUALYPSOSSOUT, iEff, nameScenario,
  probCI = 0.9, col = NULL, ylim = NULL, xlab = "Years",
  ylab = "Change variable", addLegend = TRUE, ...)
```

Arguments

QUALYPSOSSOUT	output from QUALYPSOSS
iEff	index in scenAvail corresponding to the scenarios (e.g. RCP scenarios)
nameScenario	name of the scenario to be plotted (as provided in scenAvail)
probCI	probability for the dredible interval, =0.9 by default
col	colors for each source of uncertainty, the first two colors corresponding to internal variability and residual variability, respectively
ylim	y-axis limits

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

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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

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

- **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.
- **nCluster**: number of clusters used for the parallelization (default: 1). When `nCluster` is greater than one, parallelization is used to apply `QUALYPSOSS` over multiple time steps or grid points simultaneously.

- **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.

`RK` Reproducing kernels: list

Value

list with the following fields:

- **MEAN**: list containing the mean estimate of different quantities: `ResidualVariability` (residual variability), `InternalVariability` (internal variability), `lambda` (smoothing parameters), `grandMean` (grand mean for all time steps), `effect` (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`).
- **QUANT**: list containing quantiles of different estimated quantities, listed in **MEAN**.
- **DECOMPVAR**: list with the contribution of all components to the total uncertainty, provided in `TotalVar` for all time steps. In addition, for each discrete predictor, `ContribEffect` provides the relative contribution of possible discrete value (e.g. the contribution of one RCM to the uncertainty due to RCMs).
- **MCMC.list**: 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 (to be used as an argument in `QUALYPSOSSlight`)
- **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 (to be used as an argument in `QUALYPSOSSlight`)

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)
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)

# plotQUALYPSOSSTotalVarianceByScenario draws the total uncertainty and the mean effect,
# for one discrete predictor, usually a RCP scenario (e.g. it provides an illustration of the
```

```
# future evolution and associated uncertainties for one RCP scenario).
plotQUALYPSOSSTotalVarianceByScenario(QUALYPSOSSOUT,nameScenario = "GCM1",iEff = 1)

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

QUALYPSOSS.ANOVA *QUALYPSOSS.ANOVA*

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.

Usage

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

Arguments

lOpt	list of options, returned by QUALYPSOSS.check.option
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**: Smooth effects g: array n x nFull x L where nFull is the number of possible combinations of predictors (discrete AND continuous),
- **lambda**: Smoothing parameters: matrix n x L,
- **sigma2**: Residual variance: vector of length n,
- **MCMC.list**: list containing previous objects, for records (according to the option returnMCMC).

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, nCluster)
```

Arguments

X	matrix of predictors
nK	number of discrete predictors
nCluster	number of clusters used to compute the reproducing kernels

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

QUALYPSOSSlight *QUALYPSOSSlight*

Description

same as QUALYPSOSS, but less outputs are returned, and arguments are mandatory, in order to limit processing tasks which are repeated over a grid.

Usage

```
QUALYPSOSSlight(ClimateProjections, scenAvail, predCont, predContUnique,
  iCpredCont, iCpredContUnique, listOption, lScen, RK, listCR)
```

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.

`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

- **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.
- **nCluster**: number of clusters used for the computation of reproducing kernels (default: 1). When `nCluster` is greater than one, parallelization is used to apply `QUALYPSOSS` over multiple time steps or grid points simultaneously.
- **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 `FALSE` (default), the list `MCMC` is empty in the returned object.

`lScen`
: list of objects related to the scenario characteristics: item of the list obtained from `QUALYPSOSS`

`RK`
: Reproducing kernels: item of the list obtained from `QUALYPSOSS`

`listCR`
: Object for the extraction of the climate response: item of the list obtained from `QUALYPSOSS`

Value

list with the following fields:

- **MEAN**: list containing the mean estimate of different quantities: `ResidualVariability` (residual variability), `InternalVariability` (internal variability), `lambda` (smoothing parameters), `grandMean` (grand mean for all time steps), `effect` (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`).
- **QUANT**: list containing quantiles of different estimated quantities, listed in **MEAN**.
- **DECOMPVAR**: list with the contribution of all components to the total uncertainty, provided in `TotalVar` for all time steps. In addition, for each discrete predictor, `ContribEffect` provides the relative contribution of possible discrete value (e.g. the contribution of one RCM to the uncertainty due to RCMs).

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

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