Package 'QUALYPSO'

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Title Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections

Version 1.1

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Imports MASS, expm, Rfast, foreach, doParallel, methods, stats, graphics, grDevices

Description These functions use data augmentation and Bayesian techniques for the assessment of single-member and incomplete ensembles of climate projections. It provides unbiased estimates of climate change responses of all simulation chains and of all uncertainty variables. It additionally propagates uncertainty due to missing information in the estimates. - 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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NeedsCompilation no

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R topics documented:

`fit.climate.response` *fit.climate.response*

Description

Fit trends for each simulation chain of an ensemble of `nS` projections. Each simulation chain is a time series of `nY` time steps (e.g. number of years).

Usage

```
fit.climate.response(Y, parSmooth, indexReferenceYear, typeChangeVariable)
```

Arguments

`Y`	matrix of simulation chains: `nS` x `nY`
`parSmooth`	smoothing parameter `spar` in `smooth.spline`: varies in [0,1]
`indexReferenceYear`	index of the reference year
`typeChangeVariable`	type of change variable: "abs" or "rel"

Details

See `QUALYPSO` for further information on arguments `indexReferenceYear` and `typeChangeVariable`.

Value

list with the following fields for each simulation chain:

- **phiStar**: climate change response
- **etaStar**: internal variability
- **phi**: raw trend obtained using smooth.spline
- **climateResponse**: output from smooth.spline
- **varInterVariability**: scalar, internal variability component of the MME

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. https://doi.org/10.1175/JCLI-D-18-0606.1.

`get.Qmat` *get.Qmat*

Description

Provide matrix Q derived from a matrix Q* of Helmert contrasts:

$$Q = Q^*(Q^{*T}Q^*)^{-1/2}$$

See Eq. A6 in Evin et al., 2019.

Usage

```
get.Qmat(p)
```

Arguments

`p`	integer

Value

`matrix`	p x p matrix

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. https://doi.org/10.1175/JCLI-D-18-0606.1.

get.Qstar.mat *get.Qstar.mat*

Description

Provide matrix containing Helmert contrasts (see Eq. A7 in Evin et al., 2019).

Usage

```
get.Qstar.mat(p)
```

Arguments

p	integer

Value

matrix	p x (p-1) matrix containing Helmert contrasts

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. (2019) <doi:10.1175/JCLI-D-18-0606.1>.

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. https://doi.org/10.1175/JCLI-D-18-0606.1.

plotQUALYPSOeffect *plotQUALYPSOeffect*

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

```
plotQUALYPSOeffect(QUALYPSOOUT, iEff, includeMean = FALSE,
  CIlevel = c(0.025, 0.975), lim = NULL, col = 1:20,
  xlab = "Years", ylab = "Effect", addLegend = TRUE, ...)
```

Arguments

QUALYPSOOUT	output from QUALYPSO
iEff	index of the main effect to be plotted in QUALYPSOOUT$listScenarioInput$listEff
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

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plotQUALYPSOgrandmean *plotQUALYPSOgrandmean*

Description

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

Usage

```
plotQUALYPSOgrandmean(QUALYPSOOUT, CIlevel = c(0.025, 0.975),
  lim = NULL, col = "black", xlab = "Years", ylab = "Grand mean",
  addLegend = T, ...)
```

Arguments

QUALYPSOOUT	output from QUALYPSO
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

plotQUALYPSOTotalVarianceByScenario
plotQUALYPSOTotalVarianceByScenario

Description

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

Usage

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

Arguments

QUALYPSOOUT	output from QUALYPSO
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 credible 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

plotQUALYPSOTotalVarianceDecomposition
plotQUALYPSOTotalVarianceDecomposition

Description

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

Usage

```
plotQUALYPSOTotalVarianceDecomposition(QUALYPSOOUT, vecEff = NULL,
  col = c("orange", "yellow", "cadetblue1", "blue1", "darkgreen",
  "darkgoldenrod4", "darkorchid1"), xlab = "Years",
  ylab = "% Total Variance", addLegend = TRUE, ...)
```

Arguments

QUALYPSOOUT	output from QUALYPSO
vecEff	vector of indices corresponding to the main effects (NULL by default), so that the order of appearance in the plot can be modified
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

QUALYPSO *QUALYPSO*

Description

Partition uncertainty in climate responses using an ANOVA inferred with a Bayesian approach.

Usage

```
QUALYPSO(Y, scenAvail, vecYears = NULL, indexReferenceYear = NULL,
  indexFutureYear = NULL, listOption = NULL)
```

Arguments

Y	matrix nS x nY or array nG x nS x nY of climate projections
scenAvail	matrix of available combinations nS x nEff. The number of characteristics nEff corresponds to the number of main effects which will be included in the ANOVA model.
vecYears	(optional) vector of years corresponding to the projections (e.g. vecYears=2001:2100. Optional, mainly used for records. By default, a vector 1:nY is created.

`indexReferenceYear`
: (optional) index in `vecYears` corresponding to the control year. For example, if `vecYears=1980:2100` and we want to specify a control year equals to 1990, we indicate `indexReferenceYear=11` or, equivalently `indexReferenceYear=which(vecYears==1990)` **if** `vecYears` is already available in the workspace

`indexFutureYear`
: index in `indexFutureYear` corresponding to a future year (similarly to `indexReferenceYear`). This index is necessary when `Y` is an array `nG` x `nS` x `nY` available for `nG` grid points. Indeed, in this case, we run QUALYPSO only for one future year.

`listOption`
: (optional) list of options

- **parSmooth**: smoothing parameter `spar` in smooth.spline: varies in [0,1]
- **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 `QUALYPSO` over multiple time steps or grid points simultaneously.
- **doCompress**: logical, indicates if all the samples from the posterior distributions are stored (if FALSE) or if only quantiles are retrieved (if TRUE). Equals TRUE by default
- **computeEmpEff**: vector of column indices in `scenAvail` corresponding to effects which are estimated empirically (e.g. interactions) when the number of available runs is not sufficient to identify / estimate these additional effects.
- **quantileCompress**: vector of probabilities (in [0,1]) for which we compute the quantiles from the posterior distributions `quantileCompress = c(0.005,0.025,0.05,0.1,0.2` by default

Value

list with the following fields:

- **CLIMATEESPONSE**: list of climate change responses and corresponding internal variability. Contains `phiStar` (climate change responses), `etaStar` (deviation from the climate change responses as a result of internal variability), and `phi` (fitted climate responses)
- **ANOVAPOST**: list of MCMC samples representing the posterior distributions of inferred quantities. `=NULL` if`listOption$doCompress=T`
- **ANOVAQUANT**: list of quantiles from the posterior distributions of inferred quantities
- **ANOVAMEAN**: list of mean of the posterior distributions of inferred quantities Each element contains the main effects (e.g. number of GCMs, RCMs, etc.)
- **ANOVAVARIANCE**: matrix `nTypeEff` x `nY` of variances related to the main effects
- **vecYears**: vector of years

- **vecYearsANOVA**: vector of years for the ANOVA decomposition (start at `indexReferenceYear`)
- **Y**: matrix of available combinations given as inputs
- **listOption**: list of options used to obtained these results (obtained from `QUALYPSO.check.option`)
- **listScenarioInput**: list of scenario characteristics (obtained from `QUALYPSO.process.scenario`)

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. https://doi.org/10.1175/JCLI-D-18-0606.1.

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)
Y = rbind(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'))

##############################################################################
# RUN QUALYPSO
##############################################################################
# call main QUALYPSO function: two arguments are mandatory:
# - Y: Climate projections for nS scenarions and nY time steps. if Y is a matrix nS x nY, we
# run QUALYPSO nY times, for each time step. If Y is an array nG x nS x nY, for nG grid points,
# we run QUALYPSO nG times, for each grid point, for one time step specified using the argument
```

```
# indexFutureYear.
# - scenAvail: matrix or data.frame of available combinations nS x nEff. The number of
# characteristics nEff corresponds to the number of main effects which will be included in the
# ANOVA model. In the following example, we have nEff=2 main effects corresponding to the GCMs
# and RCMs.

# Many options can be specified in the argument "listOption". Here, we change the default values
# for nBurn and nKeep in order to speed up computation time for this small example. However, it must
# be noticed that convergence and sampling of the posterior distributions often require higher
# values for these two parameters.
listOption = list(nBurn=100,nKeep=100,quantileCompress=c(0.025,0.5,0.975))

# run QUALYPSO
QUALYPSOOUT = QUALYPSO(Y=Y, scenAvail=scenAvail, vecYears=2001:2020, listOption=listOption)

##############################################################################
# SOME PLOTS
##############################################################################
# plot grand mean
plotQUALYPSOgrandmean(QUALYPSOOUT)

# plot main GCM effects
plotQUALYPSOeffect(QUALYPSOOUT,iEff=1)

# plot main RCM effects
plotQUALYPSOeffect(QUALYPSOOUT,iEff=2)

# plot fraction of total variance for the differences sources of uncertainty
plotQUALYPSOTotalVarianceDecomposition(QUALYPSOOUT)

# plot mean prediction and total variance with the differences sources of uncertainty
# for one scenario (e.g. a RCP scenario)
plotQUALYPSOTotalVarianceByScenario(QUALYPSOOUT,iEff=1,nameScenario='GCM1')
```

QUALYPSO.ANOVA *QUALYPSO.ANOVA*

Description

Partition uncertainty in climate responses using an ANOVA inferred with a Bayesian approach.

Usage

```
QUALYPSO.ANOVA(phiStar, scenAvail, listOption = NULL)
```

Arguments

phiStar	matrix of climate change responses (absolute or relative changes): nS x n. n can be the number of time steps or the number of grid points

scenAvail	matrix of available combinations nS x nEff
listOption	list of options (see QUALYPSO)

Value

list with the following fields:

- **POSTERIOR**: list of MCMC samples representing the posterior distributions of inferred quantities. =NULL iflistOption$doCompress=T
- **QUANT**: list of quantiles from the posterior distributions of inferred quantities
- **MEAN**: list of mean of the posterior distributions of inferred quantities
- **varEffect**: matrix nEff x n of variances related to the main effects
- **varResidualEffect**: vector of length n of variances of residual effects
- **listOption**: list of options used to obtained these results (obtained from QUALYPSO.check.option)
- **listScenarioInput**: list of scenario characteristics (obtained from QUALYPSO.process.scenario)

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. https://doi.org/10.1175/JCLI-D-18-0606.1.

QUALYPSO.ANOVA.i *QUALYPSO.ANOVA.i*

Description

Partition sources of uncertainty in climate change responses for one lead time or one grid point.

Usage

```
QUALYPSO.ANOVA.i(phiStar.i, nMCMC, listScenarioInput)
```

Arguments

phiStar.i	vector of nS climate change response for one lead time or for one grid point: nS x 1
nMCMC	number of MCMC simulation required
listScenarioInput	list containing specifications, provided by QUALYPSO.process.scenario

Value

list with the following fields:

- **mu**: vector of length nMCMC, mean climate change response
- **sigma2**: vector of length nMCMC, variance of the residual terms
- **effect**: list with nTypeEff elements, where each element corresponds to a different type of effect (e.g. alpha, beta, gamma in Eq. 7)
- **empEff**: list with nTypeEmpEff elements, where each element corresponds to an empirical effect Each element is a matrix nMCMC x nMaineff, and nMaineff is the number of main effects (e.g. number of GCMs, RCMs, etc.)

Author(s)

Guillaume Evin

References

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie. Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. https://doi.org/10.1175/JCLI-D-18-0606.1.

QUALYPSO.check.option *QUALYPSO.check.option*

Description

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

Usage

```
QUALYPSO.check.option(listOption)
```

Arguments

listOption	list of options

Value

List containing the complete set of options.

Author(s)

Guillaume Evin

QUALYPSO.process.scenario *QUALYPSO.process.scenario*

Description

Process input scenarios.

Usage

```
QUALYPSO.process.scenario(scenAvail, computeEmpEff)
```

Arguments

scenAvail	matrix of available combinations nS x nEff
computeEmpEff	vector of column indices in scenAvail corresponding to effects which are estimated empirically

Value

list of preprocessed objects (listEff, scenAvail, scenComp, nEff, nTypeEff, nComp, isMissing, nMissing, iMat

Author(s)

Guillaume Evin

Index