Package 'QUALYPSO'

January 20, 2025

Type Package

Date 2023-10-24

License GPL-3

Title Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections

Version 2.3

Author Guillaume Evin [aut, cre]

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

Imports MASS, expm, Rfast, 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>.

Depends R (>= 2.10)

Encoding UTF-8

LazyData true

RoxygenNote 7.2.3

NeedsCompilation no

Repository CRAN

Date/Publication 2023-10-24 07:30:02 UTC

Contents

fit.climate.response 2
get.Qmat 3
get.Qstar.mat 4
lm.ANOVA 5
plotQUALYPSOclimateChangeResponse 6
plotQUALYPSOclimateResponse 6

plotQUALYPSOeffect . . . 7
plotQUALYPSOgrandmean . . . 8
plotQUALYPSOMeanChangeAndUncertainties . . . 9
plotQUALYPSOMeanChangeAndUncertaintiesBetatest . . . 10
plotQUALYPSOTotalVarianceByScenario . . . 10
plotQUALYPSOTotalVarianceDecomposition . . . 11
QUALYPSO . . . 12
QUALYPSO.ANOVA . . . 17
QUALYPSO.ANOVA.i . . . 19
QUALYPSO.check.option . . . 20
QUALYPSO.process.scenario . . . 20
scenAvail . . . 21
Xfut_globaltas . . . 21
Xfut_time . . . 22
X_globaltas . . . 22
X_time_mat . . . 23
X_time_vec . . . 23
Y . . . 24

Index **25**

`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, args.smooth.spline, Xmat, Xfut, typeChangeVariable)
```

Arguments

`Y`	matrix of simulation chains: `nS` x `nY`
`args.smooth.spline`	list of arguments to be passed to `smooth.spline`. The `names` attribute of `args.smooth.spline` gives the argument names (see `do.call`).
`Xmat`	matrix of predictors corresponding to the projections, e.g. time or global temperature.
`Xfut`	values of the predictor over which the ANOVA will be applied.
`typeChangeVariable`	type of change variable: "abs" (absolute, value by default) or "rel" (relative)

Details

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

Value

list with the following fields for each simulation chain:

- **YStar**: `nS x nY`, change variable
- **phiStar**: `nS x nF`, climate change responses
- **etaStar**: `nS x nY`, deviation from the climate change response due to the internal variability, for `Xmat`
- **phi**: `nS x nF`, raw trends 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 (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. <doi: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 (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. <doi: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 (2020) <doi:10.1175/JCLI-D-18-0606.1>.

Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfaillie (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. J. Climate, 32, 2423–2440. <doi:10.1175/JCLI-D-18-0606.1>.

lm.ANOVA *lm.ANOVA*

Description

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

Usage

```
lm.ANOVA(phiStar, scenAvail, listOption = NULL, namesEff)
```

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	data.frame `nS` x `nEff` with the `nEff` characteristics (e.g. type of GCM) for each of the `nS` x `nS` scenarios
listOption	list of options (see `QUALYPSO`)
namesEff	names of the main effects

Value

list with the following fields:

- **GRANDMEAN**: List of estimates for the grand mean:
  - strong: MEAN: vector of length `n` of means
  - strong: SD: vector of length `n` of standard dev.
  - strong: CI: matrix `n` x 2 of credible intervals of probability `probCI` given in `listOption`.
- **RESIDUALVAR**: List of estimates for the variance of the residual errors:
  - strong: MEAN: vector of length `n`
- **MAINEFFECT**: List of estimates for the main effects. For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - strong: MEAN: matrix `n` x `nTypeEff`
- **CHANGEBYEFFECT**: For each main effect, list of estimates for the mean change by main effect, i.e. mean change by scenario (RCP4.5). For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - strong: MEAN: matrix `n` x `nTypeEff`
- **EFFECTVAR**: variability related to the main effects (i.e. variability between the different RCMs, GCMs,..). Matrix `n` x `nTypeEff`
- **CONTRIB_EACH_EFFECT**: Contribution of each individual effect to its component (percentage), e.g. what is the contribution of GCM1 to the variability related to GCMs. For each main effect (GCM, RCM,..), each element of the list contains a matrix `n` x `nTypeEff`
- **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

---

plotQUALYPSOclimateChangeResponse

plotQUALYPSOclimateChangeResponse

Description

Plot climate change responses.

Usage

```
plotQUALYPSOclimateChangeResponse(
  QUALYPSOOUT,
  lim = NULL,
  xlab = "",
  ylab = "Climate change response",
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`lim`	y-axis limits (default is NULL)
`xlab`	x-axis label
`ylab`	y-axis label
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

---

plotQUALYPSOclimateResponse

plotQUALYPSOclimateResponse

Description

Plot the climate responses.

Usage

```
plotQUALYPSOclimateResponse(
  QUALYPSOOUT,
  lim = NULL,
  xlab = "X",
  ylab = "Y",
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`lim`	y-axis limits (default is NULL)
`xlab`	x-axis label
`ylab`	y-axis label
`...`	additional arguments to be passed to `plot`

Author(s)

Guillaume Evin

`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,
  nameEff,
  includeMean = FALSE,
  lim = NULL,
  col = 1:20,
  xlab = "",
  ylab = "Effect",
  addLegend = TRUE,
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`nameEff`	name of the main effect to be plotted in `QUALYPSOOUT$namesEff`
`includeMean`	if TRUE, the grand mean is added to the main effect in the plot
`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

`plotQUALYPSOgrandmean` *plotQUALYPSOgrandmean*

Description

Plot prediction of grand mean ensemble.

Usage

```
plotQUALYPSOgrandmean(
  QUALYPSOOUT,
  lim = NULL,
  col = "black",
  xlab = "",
  ylab = "Grand mean",
  addLegend = T,
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`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

---

plotQUALYPSOMeanChangeAndUncertainties
plotQUALYPSOMeanChangeAndUncertainties

Description

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

Usage

```
plotQUALYPSOMeanChangeAndUncertainties(
  QUALYPSOOUT,
  col = NULL,
  ylim = NULL,
  xlab = "",
  ylab = "Change variable",
  addLegend = TRUE,
  ...
)
```

Arguments

QUALYPSOOUT	output from QUALYPSO
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

`plotQUALYPSOMeanChangeAndUncertaintiesBetatest`
plotQUALYPSOMeanChangeAndUncertaintiesBetatest

Description

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

Usage

```
plotQUALYPSOMeanChangeAndUncertaintiesBetatest(
  QUALYPSOOUT,
  col = NULL,
  ylim = NULL,
  xlab = "",
  ylab = "Change variable",
  addLegend = TRUE,
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`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

`plotQUALYPSOTotalVarianceByScenario`
plotQUALYPSOTotalVarianceByScenario

Description

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

Usage

```
plotQUALYPSOTotalVarianceByScenario(
  QUALYPSOOUT,
  nameEff,
  nameScenario,
  col = NULL,
  ylim = NULL,
  xlab = "",
  ylab = "Change variable",
  addLegend = TRUE,
  ...
)
```

Arguments

`QUALYPSOOUT`	output from `QUALYPSO`
`nameEff`	name of the main effect to be plotted in `QUALYPSOOUT$namesEff`
`nameScenario`	name of the scenario to be plotted (as provided in `scenAvail`)
`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 = "",
  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 applied to climate change responses.

Usage

```
QUALYPSO(Y, scenAvail, X = NULL, Xfut = NULL, iFut = NULL, listOption = NULL)
```

Arguments

- `Y` — matrix `nS` x `nY` or array `nG` x `nS` x `nY` of climate projections.
- `scenAvail` — data.frame `nS` x `nEff` with the `nEff` characteristics (e.g. type of GCM) for each of the `nS` scenarios. The number of characteristics `nEff` corresponds to the number of main effects that will be included in the ANOVA model.
- `X` — (optional) predictors corresponding to the projections, e.g. time or global temperature. It can be a vector if the predictor is the same for all scenarios (e.g. `X=2001:2100`) or a matrix of the same size as Y if these predictors are different for the scenarios. By default, a vector `1:nY` is created.
- `Xfut` — (optional) `nF` values of the predictor over which the ANOVA will be applied. It must be a vector of values within the range of values of X. By default, it corresponds to X if X is a vector, `1:nY` if X is `NULL` or a vector of 10 values equally spaced between the minimum and maximum values of X if X is a matrix.
- `iFut` — index in `1:nF` corresponding to a future predictor value . 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 predictor. The first value defines the reference period or warming level.
- `listOption` — (optional) list of options
  - **args.smooth.spline**: list of arguments to be passed to `smooth.spline`. The `names` attribute of `args.smooth.spline` gives the argument names (see `do.call`). The default option runs `smooth.spline` with `spar=1`.
  - **typeChangeVariable**: type of change variable: "abs" (absolute, value by default) or "rel" (relative).
  - **ANOVAmethod**: ANOVA method: "QUALYPSO" applies the method described in Evin et al. (2020), "lm" applies a simple linear model to estimate the main effects.
  - **nBurn**: if `ANOVAmethod=="QUALYPSO"`, number of burn-in samples (default: 1000). If `nBurn` is too small, the convergence of MCMC chains might not be obtained.
  - **nKeep**: if `ANOVAmethod=="QUALYPSO"`, number of kept samples (default: 2000). If `nKeep` is too small, MCMC samples might not represent correctly the posterior distributions of inferred parameters.
  - **probCI**: probability (in [0,1]) for the confidence intervals, `probCI = 0.9` by default.
  - **quantilePosterior**: vector of probabilities (in [0,1]) for which we compute the quantiles from the posterior distributions `quantilePosterior = c(0.005,0.025,0.05,0.1,0.25,0.33,0.5,0.66,0.75,0.9,0.95,0.975,0.995)` by default.
  - **climResponse**: NULL by default. If it is provided, it must correspond to the outputs of `fit.climate.response`, i.e. a list with `YStar` [nS x nY], `phiStar` [nS x nF], `etaStar` [nS x nY], `phi` [nS x nF] and `varInterVariability` [scalar] if `Y` is a matrix [nS x nY], or a list with `phiStar` [nG x nS x nF], `etaStar` [nG x nS x nY], `phi` [nG x nS x nF] and `varInterVariability` vector of length `nG` if `Y` is an array [nG x nS x nY].

Value

List providing the results for each of the n values of Xfut if Y is a matrix or for each grid point if Y is an array, with the following fields:

- **CLIMATERESPONSE**: 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), Ystar (change variable from the projections),and phi (fitted climate responses).
- **GRANDMEAN**: List of estimates for the grand mean:
  - **MEAN**: vector of length n of means.
  - **SD**: vector of length n of standard dev. if ANOVAmethod=="QUALYPSO".
  - **CI**: matrix n x 2 of credible intervals of probability probCI given in listOption if ANOVAmethod=="QUALYPSO".
  - **QUANT**: matrix n x nQ of quantiles of probability quantilePosterior given in listOption if ANOVAmethod=="QUALYPSO".
- **MAINEFFECT**: List of estimates for the main effects. For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - **MEAN**: matrix n x nTypeEff
  - **SD**: matrix n x nTypeEff of standard dev. if ANOVAmethod=="QUALYPSO".
  - **CI**: array n x 2 x nTypeEff of credible intervals of probability probCI given in listOption if ANOVAmethod=="QUALYPSO".
  - **QUANT**: array n x nQ x nTypeEff of quantiles of probability quantilePosterior given in listOption if ANOVAmethod=="QUALYPSO".
- **CHANGEBYEFFECT**: For each main effect, list of estimates for the mean change by main effect, i.e. mean change by scenario. For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - **MEAN**: matrix n x nTypeEff
  - **SD**: matrix n x nTypeEff of standard dev. if ANOVAmethod=="QUALYPSO".
  - **CI**: array n x 2 x nTypeEff of credible intervals of probability probCI given in listOption if ANOVAmethod=="QUALYPSO".
  - **QUANT**: array n x nQ x nTypeEff of quantiles of probability quantilePosterior given in listOption if ANOVAmethod=="QUALYPSO".
- **EFFECTVAR**: Matrix n x nTypeEff giving, for each time variability related to the main effects (i.e. variability between the different RCMs, GCMs,..).
- **CONTRIB_EACH_EFFECT**: Contribution of each individual effect to its component (percentage), e.g. what is the contribution of GCM1 to the variability related to GCMs. For each main effect (GCM, RCM,..), each element of the list contains a matrix n x nTypeEff
- **RESIDUALVAR**: List of estimates for the variance of the residual errors:
  - **MEAN**: vector of length n.
  - **SD**: vector of length n of standard dev. if ANOVAmethod=="QUALYPSO".
  - **CI**: matrix n x 2 of credible intervals of probability probCI given in listOption if ANOVAmethod=="QUALYPSO".
  - **QUANT**: matrix n x nQ of quantiles of probability quantilePosterior given in listOption if ANOVAmethod=="QUALYPSO".

- **INTERNALVAR**: Internal variability (constant over time)
- **TOTALVAR**: total variability, i.e. the sum of internal variability, residual variability and variability related to the main effects
- **DECOMPVAR**: Decomposition of the total variability for each component
- **RESERR**: differences between the climate change responses and the additive anova formula (grand mean + main effects)
- **Xmat**: matrix of predictors
- **Xfut**: future predictor values
- **paralType**: type of parallelisation (Time or Grid)
- **namesEff**: names of the main effects
- **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 (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. <doi: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.synth = 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.synth = 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 scenarios 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
# iFut
# - scenAvail: matrix or data.frame of available combinations nS x nEff. The number of
# characteristics nEff corresponds to the number of main effects that 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". When ANOVAmethod=="QUALYPSO"
# a Bayesian inference is performed. 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 arguments.
listOption = list(nBurn=100,nKeep=100,ANOVAmethod="QUALYPSO",quantilePosterior=c(0.025,0.5,0.975))

# run QUALYPSO
QUALYPSO.synth = QUALYPSO(Y=Y.synth, scenAvail=scenAvail.synth, X=2001:2020, listOption=listOption)

##########################################################################
# SOME PLOTS
##########################################################################
# plot grand mean
plotQUALYPSOgrandmean(QUALYPSO.synth,xlab="Years")

# plot main GCM effects
plotQUALYPSOeffect(QUALYPSO.synth,nameEff="GCM",xlab="Years")

# plot main RCM effects
plotQUALYPSOeffect(QUALYPSO.synth,nameEff="RCM",xlab="Years")

# plot fraction of total variance for the differences sources of uncertainty
plotQUALYPSOTotalVarianceDecomposition(QUALYPSO.synth,xlab="Years")

# plot mean prediction and total variance with the differences sources of uncertainty
plotQUALYPSOMeanChangeAndUncertainties(QUALYPSO.synth,xlab="Years")

#____________________________________________________________
# EXAMPLE OF QUALYPSO WHEN THE PREDICTOR IS TIME
#____________________________________________________________

# list of options
listOption = list(typeChangeVariable='abs')
```

```
# call QUALYPSO
QUALYPSO.time = QUALYPSO(Y=Y,scenAvail=scenAvail,X=X_time_vec,
                         Xfut=Xfut_time,listOption=listOption)

# grand mean effect
plotQUALYPSOgrandmean(QUALYPSO.time,xlab="Years")

# main GCM effects
plotQUALYPSOeffect(QUALYPSO.time,nameEff="GCM",xlab="Years")

# main RCM effects
plotQUALYPSOeffect(QUALYPSO.time,nameEff="RCM",xlab="Years")

# mean change and associated uncertainties
plotQUALYPSOMeanChangeAndUncertainties(QUALYPSO.time,xlab="Years")

# variance decomposition
plotQUALYPSOTotalVarianceDecomposition(QUALYPSO.time,xlab="Years")

#_____________________________________________________________
# EXAMPLE OF QUALYPSO WHEN THE PREDICTOR IS THE GLOBAL TEMPERATURE
#_____________________________________________________________

# list of options
listOption = list(typeChangeVariable='abs')

# call QUALYPSO
QUALYPSO.globaltas = QUALYPSO(Y=Y,scenAvail=scenAvail,X=X_globaltas,
                              Xfut=Xfut_globaltas,listOption=listOption)

# grand mean effect
plotQUALYPSOgrandmean(QUALYPSO.globaltas,xlab="Global warming (Celsius)")

# main GCM effects
plotQUALYPSOeffect(QUALYPSO.globaltas,nameEff="GCM",xlab="Global warming (Celsius)")

# main RCM effects
plotQUALYPSOeffect(QUALYPSO.globaltas,nameEff="RCM",xlab="Global warming (Celsius)")

# mean change and associated uncertainties
plotQUALYPSOMeanChangeAndUncertainties(QUALYPSO.globaltas,xlab="Global warming (Celsius)")

# variance decomposition
plotQUALYPSOTotalVarianceDecomposition(QUALYPSO.globaltas,xlab="Global warming (Celsius)")
```

`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, namesEff)
```

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	data.frame nS x nEff with the nEff characteristics (e.g. type of GCM) for each of the nS x nS scenarios
listOption	list of options (see QUALYPSO)
namesEff	names of the main effects

Value

list with the following fields:

- **GRANDMEAN**: List of estimates for the grand mean:
  - strong: MEAN: vector of length n of posterior means
  - strong: SD: vector of length n of posterior standard dev.
  - strong: CI: matrix n x 2 of credible intervals of probability probCI given in listOption.
  - strong: QUANT: matrix n x nQ of quantiles related to the probabilities quantilePosterior given in listOption
- **RESIDUALVAR**: List of estimates for the variance of the residual errors:
  - strong: MEAN: vector of length n of posterior means
  - strong: SD: vector of length n of posterior standard dev.
  - strong: CI: matrix n x 2 of credible intervals of probability probCI given in listOption.
  - strong: QUANT: matrix n x nQ of quantiles related to the probabilities quantilePosterior given in listOption
- **MAINEFFECT**: List of estimates for the main effects. For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - strong: MEAN: matrix n x nTypeEff of posterior means
  - strong: SD: matrix n x nTypeEff of posterior standard dev.
  - strong: CI: array n x 2 x nTypeEff of credible intervals of probability probCI given in listOption.
  - strong: QUANT: array n x nQ x nTypeEff of quantiles related to the probabilities quantilePosterior given in listOption
- **CHANGEBYEFFECT**: For each main effect, list of estimates for the mean change by main effect, i.e. mean change by scenario (RCP4.5). For each main effect (GCM, RCM,..), each element of the list contains a list with:
  - strong: MEAN: matrix n x nTypeEff of posterior means
  - strong: SD: matrix n x nTypeEff of posterior standard dev.
  - strong: CI: array n x 2 x nTypeEff of credible intervals of probability probCI given in listOption.

  - strong: QUANT: array `n` x `nQ` x `nTypeEff` of quantiles related to the probabilities `quantilePosterior` given in `listOption`

- **EFFECTVAR**: variability related to the main effects (i.e. variability between the different RCMs, GCMs,..). Matrix `n` x `nTypeEff`
- **CONTRIB_EACH_EFFECT**: Contribution of each individual effect to its component (percentage), e.g. what is the contribution of GCM1 to the variability related to GCMs. For each main effect (GCM, RCM,..), each element of the list contains a matrix `n` x `nTypeEff`
- **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 (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. <doi: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) 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 (2020) Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections Using Data Augmentation. Journal of Climate. <doi: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)
```

Arguments

`scenAvail`	data.frame `nS` x `nEff` with the `nEff` characteristics (e.g. type of GCM) for each of the `nS` x `nS` scenarios

Value

list of preprocessed objects (`listEff`, `scenAvail`, `scenComp`, `nEff`, `nTypeEff`, `nComp`, `isMissing`, `nMissing`, `iMatchScen`,`indexEffInCompScen`, `Qmat`)

Author(s)

Guillaume Evin

`scenAvail` *List of 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 (obtained with the RCP8.5)

Usage

```
data(scenAvail)
```

Format

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

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`Xfut_globaltas` *Vector of of future warming levels*

Description

Equally spaced vector of of future warming levels

Usage

```
data(Xfut_globaltas)
```

Format

vector of length 13

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`Xfut_time` *Xfut_time is a vector of 11 years equally spaced from 1999 to 2099*

Description

Xfut_time is a vector of 11 years equally spaced from 1999 to 2099

Usage

```
data(Xfut_time)
```

Format

vectors of length 11

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`X_globaltas` *Annual warming levels simulated by different CMIP5 GCMs*

Description

Annual warming levels at the planetary scales simulated by different CMIP5 GCMs for the period 1971-2099. Warming levels are obtained with respect to the year 1860 (common starting year of the CMIP5 simulations). These warming levels have been obtained with the following steps:

1. Annual tas averages simulated by different CMIP5 have first been smoothed using a smoothing spline. Let us denote these smoothed values by tas_GCM(y) for a year y.
2. Large discrepancies can be observed for tas_GCM_smooth(y) even in the past due to large first-order biases in the GCM simulations. In order to obtain a common reference, we also consider observed tas estimates at the global scale. HadCRUT5 (Morice et al., 2021, 10.1029/2019JD032361) provides anomalies with respect to the period 1961-1990. An estimate of absolute average temperature for this period is 14°C (Jones et al., 1999, 10.1029/1999RG900002). Smoothed estimates of absolute tas averages are obtained using a smoothing spline and is denoted by tas_obs(y).
3. Warming levels are obtained as anomalies with respect to the period 1860 and considering a reference year, here 1990, where the warming levels WL are in agreement: WL(y) = tas_GCM(y)-tas_GCM(1990)+tas_obs(1990)-tas_obs(1860)

Usage

```
data(X_globaltas)
```

Format

matrix 20 scenarios x 129 years

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

X_time_mat — *Years 1971-2099 repeated for the 20 scenarios*

Description

Years 1971-2099 repeated for the 20 scenarios

Usage

```
data(X_time_mat)
```

Format

matrix 20 scenarios x 129 years

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

X_time_vec — *X_time_vec gives the years corr. to Y, i.e. from 1971 to 2099*

Description

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

Usage

```
data(X_time_vec)
```

Format

vector of length 129

Author(s)

Guillaume Evin <guillaume.evin@inrae.fr>

`Y` *Mean winter temperature over CEU with 20 GCM/RCM combinations for 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 20 scenarios x 129 years

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

Index

∗ **data**
scenAvail, 21
X_globaltas, 22
X_time_mat, 23
X_time_vec, 23
Xfut_globaltas, 21
Xfut_time, 22
Y, 24

do.call, *2*, *13*

fit.climate.response, 2, *13*

get.Qmat, 3
get.Qstar.mat, 4

lm.ANOVA, 5

plot, *6–12*
plotQUALYPSOclimateChangeResponse, 6
plotQUALYPSOclimateResponse, 6
plotQUALYPSOeffect, 7
plotQUALYPSOgrandmean, 8
plotQUALYPSOMeanChangeAndUncertainties, 9
plotQUALYPSOMeanChangeAndUncertaintiesBetatest, 10
plotQUALYPSOTotalVarianceByScenario, 10
plotQUALYPSOTotalVarianceDecomposition, 11

QUALYPSO, *2*, *5–12*, 12, *18*, *20*
QUALYPSO.ANOVA, 17
QUALYPSO.ANOVA.i, 19
QUALYPSO.check.option, *5*, *15*, *19*, 20
QUALYPSO.process.scenario, *5*, *15*, *19*, 20

scenAvail, 21
smooth.spline, *2*, *3*, *13*

X_globaltas, 22
X_time_mat, 23
X_time_vec, 23
Xfut_globaltas, 21
Xfut_time, 22

Y, 24