

# Package ‘QUALYPSO’

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**License** GPL-3

**Title** Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections

**Version** 2.3

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**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. Verfaille. (2019) <doi:10.1175/JCLI-D-18-0606.1>.

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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: $nS \times nY$   |
| args.smooth.spline | list of arguments to be passed to <a href="#">smooth.spline</a> . The names attribute of <code>args.smooth.spline</code> gives the argument names (see <a href="#">do.call</a> ). |
| 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): $nS \times n$ . $n$ can be the number of time steps or the number of grid points |
| scenAvail  | data.frame $nS \times nEff$ with the $nEff$ characteristics (e.g. type of GCM) for each of the $nS \times nS$ scenarios                             |
| listOption | list of options (see <a href="#">QUALYPSO</a> )   |
| 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  $n \times 2$  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  $n \times nTypeEff$
- **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  $n \times nTypeEff$
- **EFFECTVAR**: variability related to the main effects (i.e. variability between the different RCMs, GCMs,...). Matrix  $n \times nTypeEff$
- **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  $n \times nTypeEff$
- **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 <a href="#">QUALYPSO</a>                      |
| lim         | y-axis limits (default is NULL)                           |
| xlab        | x-axis label  |
| ylab        | y-axis label  |
| ...         | additional arguments to be passed to <a href="#">plot</a> |

**Author(s)**

Guillaume Evin

---

plotQUALYPSOclimateResponse  
*plotQUALYPSOclimateResponse*

---

**Description**

Plot the climate responses.

**Usage**

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

**Arguments**

|             |   |
|-------------|---|
| QUALYPSOOUT | output from <a href="#">QUALYPSO</a>                      |
| lim         | y-axis limits (default is NULL)                           |
| xlab        | x-axis label  |
| ylab        | y-axis label  |
| ...         | additional arguments to be passed to <a href="#">plot</a> |

**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 <a href="#">QUALYPSO</a>                            |
| 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 <a href="#">plot</a>       |

**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 <a href="#">QUALYPSO</a>                      |
| 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 <a href="#">plot</a> |

**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**

|                          |  |
|--------------------------|--|
| <code>QUALYPSOOUT</code> | output from <a href="#">QUALYPSO</a>   |
| <code>col</code>         | colors for each source of uncertainty, the first two colors corresponding to internal variability and residual variability, respectively |
| <code>ylim</code>        | y-axis limits  |
| <code>xlab</code>        | x-axis label   |
| <code>ylab</code>        | y-axis label   |
| <code>addLegend</code>   | if TRUE, a legend is added   |
| <code>...</code>         | additional arguments to be passed to <a href="#">plot</a>  |

**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 <a href="#">QUALYPSO</a>   |
| 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 <a href="#">plot</a>  |

**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 <a href="#">QUALYPSO</a>   |
| 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 <a href="#">plot</a>  |

**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 <a href="#">QUALYPSO</a>   |
| 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 <a href="#">plot</a>  |

**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 $nS \times nY$ or array $nG \times nS \times nY$ of climate projections.   |
| scenAvail  | data.frame $nS \times nEff$ 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 $nG \times nS \times nY$ 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 <ul style="list-style-type: none"> <li>• <b>args.smooth.spline</b>: list of arguments to be passed to <a href="#">smooth.spline</a>. The names attribute of args.smooth.spline gives the argument names (see <a href="#">do.call</a>). The default option runs smooth.spline with spar=1.</li> <li>• <b>typeChangeVariable</b>: type of change variable: "abs" (absolute, value by default) or "rel" (relative).</li> <li>• <b>ANOVAmethod</b>: ANOVA method: "QUALYPSO" applies the method described in Evin et al. (2020), "lm" applies a simple linear model to estimate the main effects.</li> <li>• <b>nBurn</b>: if ANOVAmethod=="QUALYPSO", number of burn-in samples (default: 1000). If nBurn is too small, the convergence of MCMC chains might not be obtained.</li> <li>• <b>nKeep</b>: 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.</li> <li>• <b>probCI</b>: probability (in [0,1]) for the confidence intervals, probCI = 0.9 by default.</li> <li>• <b>quantilePosterior</b>: vector of probabilities (in [0,1]) for which we compute the quantiles from the posterior distributions <code>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)</code> by default.</li> <li>• <b>climResponse</b>: NULL by default. If it is provided, it must correspond to the outputs of <a href="#">fit.climate.response</a>, i.e. a list with YStar [<math>nS \times nY</math>], phiStar [<math>nS \times nF</math>], etaStar [<math>nS \times nY</math>], phi [<math>nS \times nF</math>] and varInterVariability [scalar] if Y is a matrix [<math>nS \times nY</math>], or a list with phiStar [<math>nG \times nS \times nF</math>], etaStar [<math>nG \times nS \times nY</math>], phi [<math>nG \times nS \times nF</math>] and varInterVariability vector of length <math>nG</math> if Y is an array [<math>nG \times nS \times nY</math>].</li> </ul> |

**Value**

List providing the results for each of the  $n$  values of  $X_{fut}$  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  $\phi_{star}$  (climate change responses),  $\eta_{star}$  (deviation from the climate change responses as a result of internal variability),  $Y_{star}$  (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  $n \times 2$  of credible intervals of probability `probCI` given in `listOption` if `ANOVAmethod=="QUALYPSO"`.
  - **QUANT**: matrix  $n \times nQ$  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  $n \times nTypeEff$
  - **SD**: matrix  $n \times nTypeEff$  of standard dev. if `ANOVAmethod=="QUALYPSO"`.
  - **CI**: array  $n \times 2 \times nTypeEff$  of credible intervals of probability `probCI` given in `listOption` if `ANOVAmethod=="QUALYPSO"`.
  - **QUANT**: array  $n \times nQ \times nTypeEff$  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  $n \times nTypeEff$
  - **SD**: matrix  $n \times nTypeEff$  of standard dev. if `ANOVAmethod=="QUALYPSO"`.
  - **CI**: array  $n \times 2 \times nTypeEff$  of credible intervals of probability `probCI` given in `listOption` if `ANOVAmethod=="QUALYPSO"`.
  - **QUANT**: array  $n \times nQ \times nTypeEff$  of quantiles of probability `quantilePosterior` given in `listOption` if `ANOVAmethod=="QUALYPSO"`.
- **EFFECTVAR**: Matrix  $n \times nTypeEff$  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  $n \times nTypeEff$
- **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  $n \times 2$  of credible intervals of probability `probCI` given in `listOption` if `ANOVAmethod=="QUALYPSO"`.
  - **QUANT**: matrix  $n \times nQ$  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 <a href="#">QUALYPSO</a> )   |
| 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  $n \times nQ \times nTypeEff$  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  $n \times nTypeEff$
- **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  $n \times nTypeEff$
- **listOption**: list of options used to obtain 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

|                                |   |
|--------------------------------|---|
| <code>phiStar.i</code>         | vector of $nS$ climate change response for one lead time or for one grid point: $nS \times 1$ |
| <code>nMCMC</code>             | number of MCMC simulation required  |
| <code>listScenarioInput</code> | list containing specifications, provided by <a href="#">QUALYPSO.process.scenario</a>         |

### 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  $nMCMC \times nMaineff$ , 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 | <i>List of GCM and RCM which have been used for the 20 climate projections</i> |
|-----------|--|

---

**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 | <i>Vector of of future warming levels</i> |
|----------------|---|

---

**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  $\text{tas\_GCM}(y)$  for a year  $y$ .
2. Large discrepancies can be observed for  $\text{tas\_GCM\_smooth}(y)$  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  $\text{tas\_obs}(y)$ .
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:  $\text{WL}(y) = \text{tas\_GCM}(y) - \text{tas\_GCM}(1990) + \text{tas\_obs}(1990) - \text{tas\_obs}(1860)$

**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

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