Package 'QUALYPSO'

November 12, 2020

Type Package

Date 2020-11-11

License GPL-3

Title Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections

Version 1.2

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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>.

Depends R (>= 2.10)

Encoding UTF-8

LazyData true

RoxygenNote 6.1.1

NeedsCompilation no

Repository CRAN

Date/Publication 2020-11-12 09:00:07 UTC

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 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

`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: typically (but not necessarily) 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.
- **quantileCompress**: vector of probabilities (in [0,1]) for which we compute the quantiles from the posterior distributions `quantileCompress = c(0.005,0.025,0.05,0.1,0.25,0.33,0.5,0.66,0.75,0.9,0.95,0.975,0.995)` 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)
- **BAYES**: list of inferred quantities: quantiles from the posterior distributions are provided
  - GRANDMEAN: Grand mean
  - MAINEFFECT: Main effects
  - RESIDUALVAR_MEAN: mean of the posterior distribution for the residual variability σ^2
  - RESIDUALVAR_QUANT: quantiles of the posterior distribution for the residual variability σ^2
  - INTERNALVAR: Internal variability (constant over time)
  - EFFECTVAR: Variability related to the main effects (i.e. variability between the different RCMs, GCMs,..)
  - TOTALVAR: total variability, i.e. the sum of internal variability, residual variability and variability related to the main effect

  - DECOMPVAR: Decomposition of the total variability for each component
  - 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
  - CHANGEBYEFFECT: For each main effect, mean change by type of effect, i.e. mean change by scenario (RCP4.5)
- **POINT**: list of point estimates: mean of the posterior distributions
  - GRANDMEAN: Grand mean
  - MAINEFFECT: Main effects
  - RESIDUALVAR: Variance of residual errors computed from the differences between the climate change responses and the additive anova formula (grand mean + main effects)
  - INTERNALVAR: Internal variability (constant over time)
  - EFFECTVAR: Variability related to the main effects (i.e. variability between the different RCMs, GCMs,..)
  - TOTALVAR: total variability, i.e. the sum of internal variability, residual variability and variability related to the main effect
  - DECOMPVAR: Decomposition of the total variability for each component
  - 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
  - CHANGEBYEFFECT: For each main effect, mean change by type of effect, i.e. mean change by scenario (RCP4.5)
  - RESERR: differences between the climate change responses and the additive anova formula (grand mean + main effects)
- **vecYears**: vector of years
- **vecYearsANOVA**: vector of years for the ANOVA decomposition (start at `indexReferenceYear`)
- **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. 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:

- **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) 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)
```

Arguments

scenAvail	matrix of available combinations nS x nEff

Value

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

Author(s)

Guillaume Evin

Index