Package ‘QUALYPSO’

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Title Partitioning Uncertainty Components of an Incomplete Ensemble of Climate Projections

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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 unbi-
ased estimates of climate change responses of all simulation chains and of all uncertainty vari-
ables. It additionally propagates uncertainty due to missing information in the estimates.
- Evin, G., B. Hingray, J. Blanchet, N. Eckert, S. Morin, and D. Verfail-

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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

\[
\text{fit.climate.response}(Y, \text{parSmooth}, \text{indexReferenceYear}, \text{typeChangeVariable})
\]

Arguments

- \( Y \): matrix of simulation chains: \( nS \times nY \)
- \( \text{parSmooth} \): smoothing parameter \( \text{spar} \) in \( \text{smooth.spline} \): varies in \([0,1]\)
- \( \text{indexReferenceYear} \): index of the reference year
- \( \text{typeChangeVariable} \): type of change variable: "abs" or "rel"

Details

See QUALYPSO for further information on arguments \( \text{indexReferenceYear} \) and \( \text{typeChangeVariable} \).

Value

list with the following fields for each simulation chain:

- \( \text{phiStar} \): climate change response
- \( \text{etaStar} \): internal variability
- \( \text{phi} \): raw trend obtained using \( \text{smooth.spline} \)
- \( \text{climateResponse} \): output from \( \text{smooth.spline} \)
- \( \text{varInterVariability} \): scalar, internal variability component of the MME

Author(s)

Guillaume Evin
**get.Qmat**

**References**


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**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**

### getQstar.mat

**Description**

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

**Usage**

```r
getQstar.mat(p)
```

**Arguments**

- `p` integer

**Value**

matrix | p \times (p-1) matrix containing Helmert contrasts

**Author(s)**

Guillaume Evin

**References**


### 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**

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

Arguments

- `QUALYPSOOUT`: output from QUALYPSO
- `iEff`: index of the main effect to be plotted in QUALYPSO\$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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**Description**

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

**Usage**

```r
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

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

Description

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

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 inter-
nal 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

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:

- **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), 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

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

t = 1:n/n

# GCM effects (sums to 0 for each t)
effGCM1 = t*x2
effGCM2 = t*x-2

# RCM effects (sums to 0 for each t)
effRCM1 = t*x1
effRCM2 = t*x-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)
scenGCM2RCM2 = effGCM2 + effRCM2 + 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 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


# QUALYPSO
QUALYPSO.ANOVA

# 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

**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 $nS \times nEff$
listOption list of options (see QUALYSPO)

Value
list with the following fields:

- **POSTERIOR**: list of MCMC samples representing the posterior distributions of inferred quantities. =NULL if listOption$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 $nEff \times n$ 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 QUALYSPO.check.option)
- **listScenarioInput**: list of scenario characteristics (obtained from QUALYSPO.process.scenario)

Author(s)
Guillaume Evin

References

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

Usage
QUALYSPO.ANOVA.i(phiStar.i, nMCMC, listScenarioInput)

Arguments
- **phiStar.i**: vector of $nS$ climate change response for one lead time or for one grid point: $nS \times 1$
- **nMCMC**: number of MCMC simulation required
- **listScenarioInput**: list containing specifications, provided by QUALYSPO.process.scenario
Value

list with the following fields:

- **mu**: vector of length $n_{MCMC}$, mean climate change response
- **sigma2**: vector of length $n_{MCMC}$, variance of the residual terms
- **effect**: list with $n_{TypeEff}$ elements, where each element corresponds to a different type of effect (e.g. alpha, beta, gamma in Eq. 7)
- **empEff**: list with $n_{TypeEmpEff}$ elements, where each element corresponds to an empirical effect. Each element is a matrix $n_{MCMC} \times n_{MainEff}$, and $n_{MainEff}$ is the number of main effects (e.g. number of GCMs, RCMs, etc.)

Author(s)

Guillaume Evin

References

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, imatchscen, indexEffincomp, scen)

Author(s)

Guillaume Evin
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