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Type Package

Title Spatial Estimation and Prediction for Censored/Missing Responses

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Description It provides functions to estimate parameters in linear spatial models with censored/missing responses via the Expectation-Maximization (EM), the Stochastic Approximation EM (SAEM), or the Monte Carlo EM (MCEM) algorithm. These algorithms are widely used to compute the maximum likelihood (ML) estimates in problems with incomplete data. The EM algorithm computes the ML estimates when a closed expression for the conditional expectation of the complete-data log-likelihood function is available. In the MCEM algorithm, the conditional expectation is substituted by a Monte Carlo approximation based on many independent simulations of the missing data. In contrast, the SAEM algorithm splits the E-step into simulation and integration steps. This package also approximates the standard error of the estimates using the Louis method. Moreover, it has a function that performs spatial prediction in new locations.

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CovMat *Covariance matrix for spatial models*

Description

It computes the spatial variance-covariance matrix considering exponential, gaussian, matérn, or power exponential correlation function.

Usage

```
CovMat(phi, tau2, sig2, coords, type = "exponential", kappa = NULL)
```

Arguments

phi	spatial scaling parameter.
tau2	nugget effect parameter.
sig2	partial sill parameter.
coords	2D spatial coordinates of dimensions $n \times 2$.
type	type of spatial correlation function: 'exponential', 'gaussian', 'matern', and 'pow.exp' for exponential, gaussian, matérn, and power exponential, respectively.
kappa	parameter for some spatial correlation functions. For exponential and gaussian kappa=NULL, for power exponential 0 < kappa <= 2, and for matérn correlation function kappa > 0.

Details

The spatial covariance matrix is given by

$\Sigma = [Cov(s_i, s_j)] = \sigma^2 R(\phi) + \tau^2 I_n$,

where $\sigma^2 > 0$ is the partial sill, $\phi > 0$ is the spatial scaling parameter, $\tau^2 > 0$ is known as the nugget effect in the geostatistical framework, $R(\phi)$ is the $n \times n$ correlation matrix computed from a correlation function, and I_n is the $n \times n$ identity matrix.

The spatial correlation functions available are:

Exponential: $Corr(d) = exp(-d/\phi)$,

Gaussian: $Corr(d) = exp(-(d/\phi)^2)$,

Matérn: $Corr(d) = \frac{1}{2^{(\kappa-1)}\Gamma(\kappa)} \left(\frac{d}{\phi}\right)^{\kappa} K_\kappa \left(\frac{d}{\phi}\right)$,

Power exponential: $Corr(d) = exp(-(d/\phi)^\kappa)$,

where $d \geq 0$ is the Euclidean distance between two observations, $\Gamma(.)$ is the gamma function, κ is the smoothness parameter, and $K_\kappa(.)$ is the modified Bessel function of the second kind of order κ.

Value

An $n \times n$ spatial covariance matrix.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

See Also

dist2Dmatrix, EM.sclm, MCEM.sclm, SAEM.sclm

Examples

```
set.seed(1000)
n = 20
coords = round(matrix(runif(2*n, 0, 10), n, 2), 5)
Cov = CovMat(phi=5, tau2=0.8, sig2=2, coords=coords, type="exponential")
```

---

dist2Dmatrix *Distance matrix computation*

Description

It computes the Euclidean distance matrix for a set of coordinates.

Usage

```
dist2Dmatrix(coords)
```

Arguments

coords	2D spatial coordinates of dimensions $n \times 2$.

Value

An $n \times n$ distance matrix.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

Examples

```
n = 100
set.seed(1000)
x = round(runif(n,0,10), 5)     # X coordinate
y = round(runif(n,0,10), 5)     # Y coordinate
Mdist = dist2Dmatrix(cbind(x, y))
```

EM.sclm *ML estimation of spatial censored linear models via the EM algorithm*

Description

It fits the left, right, or interval spatial censored linear model using the Expectation-Maximization (EM) algorithm. It provides estimates and standard errors of the parameters and supports missing values on the dependent variable.

Usage

```
EM.sclm(y, x, ci, lcl = NULL, ucl = NULL, coords, phi0, nugget0,
  type = "exponential", kappa = NULL, lower = c(0.01, 0.01),
  upper = c(30, 30), MaxIter = 300, error = 1e-04, show_se = TRUE)
```

Arguments

y	vector of responses of length n.
x	design matrix of dimensions $n \times q$, where q is the number of fixed effects, including the intercept.
ci	vector of censoring indicators of length n. For each observation: `1` if censored/missing, `0` otherwise.
lcl, ucl	vectors of length n representing the lower and upper bounds of the interval, which contains the true value of the censored observation. Default `=NULL`, indicating no-censored data. For each observation: `lcl=-Inf` and `ucl=c` (left censoring); `lcl=c` and `ucl=Inf` (right censoring); and `lcl` and `ucl` must be finite for interval censoring. Moreover, missing data could be defined by setting `lcl=-Inf` and `ucl=Inf`.

`coords`	2D spatial coordinates of dimensions $n \times 2$.
`phi0`	initial value for the spatial scaling parameter.
`nugget0`	initial value for the nugget effect parameter.
`type`	type of spatial correlation function: `'exponential'`, `'gaussian'`, `'matern'`, and `'pow.exp'` for exponential, gaussian, matérn, and power exponential, respectively.
`kappa`	parameter for some spatial correlation functions. See `CovMat`.
`lower, upper`	vectors of lower and upper bounds for the optimization method. If unspecified, the default is `c(0.01,0.01)` for lower and `c(30,30)` for upper.
`MaxIter`	maximum number of iterations for the EM algorithm. By default `=300`.
`error`	maximum convergence error. By default `=1e-4`.
`show_se`	logical. It indicates if the standard errors should be estimated by default `=TRUE`.

Details

The spatial Gaussian model is given by

$Y = X\beta + \xi,$

where Y is the $n \times 1$ response vector, X is the $n \times q$ design matrix, β is the $q \times 1$ vector of regression coefficients to be estimated, and ξ is the error term. Which is normally distributed with zero-mean and covariance matrix $\Sigma = \sigma^2 R(\phi) + \tau^2 I_n$. We assume that Σ is non-singular and X has a full rank (Diggle and Ribeiro 2007).

The estimation process is performed via the EM algorithm, initially proposed by Dempster et al. (1977). The conditional expectations are computed using the function `meanvarTMD` available in the package `MomTrunc`.

Value

An object of class "sclm". Generic functions `print` and `summary` have methods to show the results of the fit. The function `plot` can extract convergence graphs for the parameter estimates.

Specifically, the following components are returned:

`Theta`	estimated parameters in all iterations, $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`theta`	final estimation of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`beta`	estimated β.
`sigma2`	estimated σ^2.
`phi`	estimated ϕ.
`tau2`	estimated τ^2.
`EY`	first conditional moment computed in the last iteration.
`EYY`	second conditional moment computed in the last iteration.
`SE`	vector of standard errors of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`InfMat`	observed information matrix.
`loglik`	log-likelihood for the EM method.

AIC	Akaike information criterion.
BIC	Bayesian information criterion.
Iter	number of iterations needed to converge.
time	processing time.
call	RcppCensSpatial call that produced the object.
tab	table of estimates.
critFin	selection criteria.
range	effective range.
ncens	number of censored/missing observations.
MaxIter	maximum number of iterations for the EM algorithm.

Note

The EM final estimates correspond to the estimates obtained at the last iteration of the EM algorithm.

To fit a regression model for non-censored data, just set `ci` as a vector of zeros.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

References

Dempster AP, Laird NM, Rubin DB (1977). "Maximum likelihood from incomplete data via the EM algorithm." *Journal of the Royal Statistical Society: Series B (Methodological)*, **39**(1), 1–38.

Diggle P, Ribeiro P (2007). *Model-based Geostatistics*. Springer.

See Also

MCEM.sclm, SAEM.sclm, predict.sclm

Examples

```
# Simulated example: 10% of left-censored observations
set.seed(1000)
n = 50   # Test with another values for n
coords = round(matrix(runif(2*n,0,15),n,2), 5)
x = cbind(rnorm(n), runif(n))
data = rCensSp(c(-1,3), 2, 4, 0.5, x, coords, "left", 0.10, 0, "gaussian")

fit = EM.sclm(y=data$y, x=x, ci=data$ci, lcl=data$lcl, ucl=data$ucl,
              coords=coords, phi0=3, nugget0=1, type="gaussian")
fit
```

MCEM.sclm *ML estimation of spatial censored linear models via the MCEM algorithm*

Description

It fits the left, right, or interval spatial censored linear model using the Monte Carlo EM (MCEM) algorithm. It provides estimates and standard errors of the parameters and supports missing values on the dependent variable.

Usage

```
MCEM.sclm(y, x, ci, lcl = NULL, ucl = NULL, coords, phi0, nugget0,
  type = "exponential", kappa = NULL, lower = c(0.01, 0.01),
  upper = c(30, 30), MaxIter = 500, nMin = 20, nMax = 5000,
  error = 1e-04, show_se = TRUE)
```

Arguments

`y`	vector of responses of length n.
`x`	design matrix of dimensions $n \times q$, where q is the number of fixed effects, including the intercept.
`ci`	vector of censoring indicators of length n. For each observation: `1` if censored/missing, `0` otherwise.
`lcl, ucl`	vectors of length n representing the lower and upper bounds of the interval, which contains the true value of the censored observation. Default `=NULL`, indicating no-censored data. For each observation: `lcl=-Inf` and `ucl=c` (left censoring); `lcl=c` and `ucl=Inf` (right censoring); and `lcl` and `ucl` must be finite for interval censoring. Moreover, missing data could be defined by setting `lcl=-Inf` and `ucl=Inf`.
`coords`	2D spatial coordinates of dimensions $n \times 2$.
`phi0`	initial value for the spatial scaling parameter.
`nugget0`	initial value for the nugget effect parameter.
`type`	type of spatial correlation function: `'exponential'`, `'gaussian'`, `'matern'`, and `'pow.exp'` for exponential, gaussian, matérn, and power exponential, respectively.
`kappa`	parameter for some spatial correlation functions. See `CovMat`.
`lower, upper`	vectors of lower and upper bounds for the optimization method. If unspecified, the default is `c(0.01,0.01)` for lower and `c(30,30)` for upper.
`MaxIter`	maximum number of iterations for the MCEM algorithm. By default `=500`.
`nMin`	initial sample size for Monte Carlo integration. By default `=20`.
`nMax`	maximum sample size for Monte Carlo integration. By default `=5000`.
`error`	maximum convergence error. By default `=1e-4`.
`show_se`	logical. It indicates if the standard errors should be estimated by default `=TRUE`.

Details

The spatial Gaussian model is given by

$Y = X\beta + \xi,$

where Y is the $n \times 1$ response vector, X is the $n \times q$ design matrix, β is the $q \times 1$ vector of regression coefficients to be estimated, and ξ is the error term. Which is normally distributed with zero-mean and covariance matrix $\Sigma = \sigma^2 R(\phi) + \tau^2 I_n$. We assume that Σ is non-singular and X has a full rank (Diggle and Ribeiro 2007).

The estimation process is performed via the MCEM algorithm, initially proposed by Wei and Tanner (1990). The Monte Carlo (MC) approximation starts with a sample of size `nMin`; at each iteration, the sample size increases (`nMax-nMin`)/`MaxIter`, and at the last iteration, the sample size is `nMax`. The random observations are sampled through the slice sampling algorithm available in package `relliptical`.

Value

An object of class "sclm". Generic functions `print` and `summary` have methods to show the results of the fit. The function `plot` can extract convergence graphs for the parameter estimates.

Specifically, the following components are returned:

`Theta`	estimated parameters in all iterations, $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`theta`	final estimation of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`beta`	estimated β.
`sigma2`	estimated σ^2.
`phi`	estimated ϕ.
`tau2`	estimated τ^2.
`EY`	MC approximation of the first conditional moment.
`EYY`	MC approximation of the second conditional moment.
`SE`	vector of standard errors of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`InfMat`	observed information matrix.
`loglik`	log-likelihood for the MCEM method.
`AIC`	Akaike information criterion.
`BIC`	Bayesian information criterion.
`Iter`	number of iterations needed to converge.
`time`	processing time.
`call`	`RcppCensSpatial` call that produced the object.
`tab`	table of estimates.
`critFin`	selection criteria.
`range`	effective range.
`ncens`	number of censored/missing observations.
`MaxIter`	maximum number of iterations for the MCEM algorithm.

Note

The MCEM final estimates correspond to the mean of the estimates obtained at each iteration after deleting the half and applying a thinning of 3.

To fit a regression model for non-censored data, just set `ci` as a vector of zeros.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

References

Diggle P, Ribeiro P (2007). *Model-based Geostatistics*. Springer.

Wei G, Tanner M (1990). "A Monte Carlo implementation of the EM algorithm and the poor man's data augmentation algorithms." *Journal of the American Statistical Association*, **85**(411), 699–704. doi:10.1080/01621459.1990.10474930.

See Also

`EM.sclm`, `SAEM.sclm`, `predict.sclm`

Examples

```
# Example 1: left censoring data
set.seed(1000)
n = 50   # Test with another values for n
coords = round(matrix(runif(2*n,0,15),n,2), 5)
x = cbind(rnorm(n), rnorm(n))
data = rCensSp(c(2,-1), 2, 3, 0.70, x, coords, "left", 0.08, 0, "matern", 1)

fit = MCEM.sclm(y=data$y, x=x, ci=data$ci, lcl=data$lcl, ucl=data$ucl,
                coords, phi0=2.50, nugget0=0.75, type="matern",
                kappa=1, MaxIter=30, nMax=1000)
fit$tab

# Example 2: left censoring and missing data
yMiss = data$y
yMiss[20] = NA
ci = data$ci
ci[20] = 1
ucl = data$ucl
ucl[20] = Inf

fit1 = MCEM.sclm(y=yMiss, x=x, ci=ci, lcl=data$lcl, ucl=ucl, coords,
                 phi0=2.50, nugget0=0.75, type="matern", kappa=1,
                 MaxIter=300, nMax=1000)
summary(fit1)
plot(fit1)
```

Missouri — *TCDD concentration data*

Description

The level of dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD) data was collected in November 1983 by the U.S. Environmental Protection Agency (EPA) in several areas of a highway in Missouri, USA. The TCDD measurement was subject to a limit of detection (`cens`); thereby, the `TCDD` data is left-censored. Only the locations used in the geostatistical analysis by Zirschky and Harris (1986) are shown.

Usage

```
data("Missouri")
```

Format

A data frame with 127 observations and five variables:

xcoord x coordinate of the start of each transect (ft).

ycoord y coordinate of the start of each transect (ft).

TCDD TCDD concentrations (mg/kg).

transect transect length (ft).

cens indicator of censoring (left-censored observations).

Source

Zirschky JH, Harris DJ (1986). "Geostatistical analysis of hazardous waste site data." *Journal of Environmental Engineering*, **112**(4), 770–784.

See Also

`EM.sclm`, `MCEM.sclm`, `SAEM.sclm`

Examples

```
data("Missouri")
y = log(Missouri$TCDD)
cc = Missouri$cens
coord = cbind(Missouri$xcoord/100, Missouri$ycoord)
x = matrix(1, length(y), 1)
lcl = rep(-Inf, length(y))
ucl = y

## SAEM fit
set.seed(83789)
fit1 = SAEM.sclm(y, x, cc, lcl, ucl, coord, 5, 1, lower=c(1e-5,1e-5),
                 upper=c(50,50))
```

```
fit1$tab

## MCEM fit
fit2 = MCEM.sclm(y, x, cc, lcl, ucl, coord, 5, 1, lower=c(1e-5,1e-5),
                 upper=c(50,50), MaxIter=300, nMax=1000)
fit2$tab

## Imputed values
cbind(fit1$EY, fit2$EY)[cc==1,]
```

`predict.sclm` *Prediction in spatial models with censored/missing responses*

Description

It performs spatial prediction in a set of new `S` spatial locations.

Usage

```
## S3 method for class 'sclm'
predict(object, locPre, xPre, ...)
```

Arguments

`object`	object of class `'sclm'` given as output of `EM.sclm`, `MCEM.sclm`, or `SAEM.sclm` function.
`locPre`	matrix of coordinates for which prediction is performed.
`xPre`	matrix of covariates for which prediction is performed.
`...`	further arguments passed to or from other methods.

Details

This function predicts using the mean squared error (MSE) criterion, which takes the conditional expectation E(Y|X) as the best linear predictor.

Value

The function returns a list with:

`coord`	matrix of coordinates.
`predValues`	predicted values.
`sdPred`	predicted standard deviations.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

See Also

EM.sclm, MCEM.sclm, SAEM.sclm

Examples

```
set.seed(1000)
n = 120
coords = round(matrix(runif(2*n,0,15),n,2), 5)
x = cbind(rbinom(n,1,0.50), rnorm(n), rnorm(n))
data = rCensSp(c(1,4,-1), 2, 3, 0.50, x, coords, "left", 0.10, 20)

## Estimation
data1 = data$Data

# Estimation: EM algorithm
fit1 = EM.sclm(y=data1$y, x=data1$x, ci=data1$ci, lcl=data1$lcl,
               ucl=data1$ucl, coords=data1$coords, phi0=2.50, nugget0=1)

# Estimation: SAEM algorithm
fit2 = SAEM.sclm(y=data1$y, x=data1$x, ci=data1$ci, lcl=data1$lcl,
                 ucl=data1$ucl, coords=data1$coords, phi0=2.50, nugget0=1)

# Estimation: MCEM algorithm
fit3 = MCEM.sclm(y=data1$y, x=data1$x, ci=data1$ci, lcl=data1$lcl,
                 ucl=data1$ucl, coords=data1$coords, phi0=2.50, nugget0=1,
                 MaxIter=300)
cbind(fit1$theta, fit2$theta, fit3$theta)

# Prediction
data2 = data$TestData
pred1 = predict(fit1, data2$coords, data2$x)
pred2 = predict(fit2, data2$coords, data2$x)
pred3 = predict(fit3, data2$coords, data2$x)

# Cross-validation
mean((data2$y - pred1$predValues)^2)
mean((data2$y - pred2$predValues)^2)
mean((data2$y - pred3$predValues)^2)
```

---

rCensSp *Censored spatial data simulation*

Description

It simulates censored spatial data with a linear structure for an established censoring rate.

Usage

```
rCensSp(beta, sigma2, phi, nugget, x, coords, cens = "left", pcens = 0.1,
  npred = 0, cov.model = "exponential", kappa = NULL)
```

Arguments

beta	linear regression parameters.
sigma2	partial sill parameter.
phi	spatial scaling parameter.
nugget	nugget effect parameter.
x	design matrix of dimensions $n \times q$.
coords	2D spatial coordinates of dimensions $n \times 2$.
cens	'left' or 'right' censoring. By default ='left'.
pcens	desired censoring rate. By default =0.10.
npred	number of simulated data used for cross-validation (Prediction). By default =0.
cov.model	type of spatial correlation function: 'exponential', 'gaussian', 'matern', and 'pow.exp' for exponential, gaussian, matérn, and power exponential, respectively.
kappa	parameter for some spatial correlation functions. For exponential and gaussian kappa=NULL, for power exponential 0 < kappa <= 2, and for matérn correlation function kappa > 0.

Value

If npred > 0, it returns two lists: Data and TestData; otherwise, it returns a list with the simulated data.

Data

y	response vector.
ci	censoring indicator.
lcl	lower censoring bound.
ucl	upper censoring bound.
coords	coordinates matrix.
x	design matrix.

TestData

y	response vector.
coords	coordinates matrix.
x	design matrix.

Author(s)

Katherine L. Valeriano, Alejandro Ordoñez, Christian E. Galarza, and Larissa A. Matos.

Examples

```
n = 100
set.seed(1000)
coords = round(matrix(runif(2*n,0,15),n,2), 5)
x = cbind(1, rnorm(n))
data = rCensSp(beta=c(5,2), sigma2=2, phi=4, nugget=0.70, x=x,
               coords=coords, cens="left", pcens=0.10, npred=10,
               cov.model="gaussian")
data$Data
data$TestData
```

`SAEM.sclm` *ML estimation of spatial censored linear models via the SAEM algorithm*

Description

It fits the left, right, or interval spatial censored linear model using the Stochastic Approximation EM (SAEM) algorithm. It provides estimates and standard errors of the parameters and supports missing values on the dependent variable.

Usage

```
SAEM.sclm(y, x, ci, lcl = NULL, ucl = NULL, coords, phi0, nugget0,
  type = "exponential", kappa = NULL, lower = c(0.01, 0.01),
  upper = c(30, 30), MaxIter = 300, M = 20, pc = 0.2, error = 1e-04,
  show_se = TRUE)
```

Arguments

`y`	vector of responses of length n.
`x`	design matrix of dimensions $n \times q$, where q is the number of fixed effects, including the intercept.
`ci`	vector of censoring indicators of length n. For each observation: `1` if censored/missing, `0` otherwise.
`lcl, ucl`	vectors of length n representing the lower and upper bounds of the interval, which contains the true value of the censored observation. Default `=NULL`, indicating no-censored data. For each observation: `lcl=-Inf` and `ucl=c` (left censoring); `lcl=c` and `ucl=Inf` (right censoring); and `lcl` and `ucl` must be finite for interval censoring. Moreover, missing data could be defined by setting `lcl=-Inf` and `ucl=Inf`.
`coords`	2D spatial coordinates of dimensions $n \times 2$.
`phi0`	initial value for the spatial scaling parameter.
`nugget0`	initial value for the nugget effect parameter.

type	type of spatial correlation function: 'exponential', 'gaussian', 'matern', and 'pow.exp' for exponential, gaussian, matérn, and power exponential, respectively.
kappa	parameter for some spatial correlation functions. See CovMat.
lower, upper	vectors of lower and upper bounds for the optimization method. If unspecified, the default is c(0.01,0.01) for lower and c(30,30) for upper.
MaxIter	maximum number of iterations of the SAEM algorithm. By default =300.
M	number of Monte Carlo samples for stochastic approximation. By default =20.
pc	percentage of initial iterations of the SAEM algorithm with no memory. It is recommended that 50<MaxIter*pc<100. By default =0.20.
error	maximum convergence error. By default =1e-4.
show_se	logical. It indicates if the standard errors should be estimated by default =TRUE.

Details

The spatial Gaussian model is given by

$Y = X\beta + \xi,$

where Y is the $n \times 1$ response vector, X is the $n \times q$ design matrix, β is the $q \times 1$ vector of regression coefficients to be estimated, and ξ is the error term which is normally distributed with zero-mean and covariance matrix $\Sigma = \sigma^2 R(\phi) + \tau^2 I_n$. We assume that Σ is non-singular and X has full rank (Diggle and Ribeiro 2007).

The estimation process is performed via the SAEM algorithm, initially proposed by Delyon et al. (1999). The spatial censored (SAEM) algorithm was previously proposed by Lachos et al. (2017) and Ordoñez et al. (2018) and is available in the package CensSpatial. These packages differ in the random number generation and optimization procedure.

This model is also a particular case of the spatio-temporal model defined by Valeriano et al. (2021) when the number of temporal observations is equal to one. The computing codes of the spatio-temporal SAEM algorithm are available in the package StempCens.

Value

An object of class "sclm". Generic functions print and summary have methods to show the results of the fit. The function plot can extract convergence graphs for the parameter estimates.

Specifically, the following components are returned:

Theta	estimated parameters in all iterations, $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
theta	final estimation of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
beta	estimated β.
sigma2	estimated σ^2.
phi	estimated ϕ.
tau2	estimated τ^2.
EY	stochastic approximation of the first conditional moment.
EYY	stochastic approximation of the second conditional moment.

`SE`	vector of standard errors of $\theta = (\beta, \sigma^2, \phi, \tau^2)$.
`InfMat`	observed information matrix.
`loglik`	log-likelihood for the SAEM method.
`AIC`	Akaike information criterion.
`BIC`	Bayesian information criterion.
`Iter`	number of iterations needed to converge.
`time`	processing time.
`call`	`RcppCensSpatial` call that produced the object.
`tab`	table of estimates.
`critFin`	selection criteria.
`range`	effective range.
`ncens`	number of censored/missing observations.
`MaxIter`	maximum number of iterations for the SAEM algorithm.

Note

The SAEM final estimates correspond to the estimates obtained at the last iteration of the algorithm.

To fit a regression model for non-censored data, just set `ci` as a vector of zeros.

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References

Delyon B, Lavielle M, Moulines E (1999). "Convergence of a stochastic approximation version of the EM algorithm." *The Annals of Statistics*, **27**(1), 94–128.

Diggle P, Ribeiro P (2007). *Model-based Geostatistics*. Springer.

Lachos VH, Matos LA, Barbosa TS, Garay AM, Dey DK (2017). "Influence diagnostics in spatial models with censored response." *Environmetrics*, **28**(7).

Ordoñez JA, Bandyopadhyay D, Lachos VH, Cabral CRB (2018). "Geostatistical estimation and prediction for censored responses." *Spatial Statistics*, **23**, 109–123. doi:10.1016/j.spasta.2017.12.001.

Valeriano KL, Lachos VH, Prates MO, Matos LA (2021). "Likelihood-based inference for spatiotemporal data with censored and missing responses." *Environmetrics*, **32**(3).

See Also

`EM.sclm`, `MCEM.sclm`, `predict.sclm`

Examples

```
# Example 1: 8% of right-censored observations
set.seed(1000)
n = 50   # Test with another values for n
coords = round(matrix(runif(2*n,0,15),n,2), 5)
x = cbind(rnorm(n), rnorm(n))
data = rCensSp(c(4,-2), 1, 3, 0.50, x, coords, "right", 0.08)

fit = SAEM.sclm(y=data$y, x=x, ci=data$ci, lcl=data$lcl, ucl=data$ucl,
                coords, phi0=2, nugget0=1, type="exponential", M=10,
                pc=0.18)
fit

# Example 2: censored and missing observations
set.seed(123)
n = 200
coords = round(matrix(runif(2*n,0,20),n,2), 5)
x = cbind(runif(n), rnorm(n), rexp(n))
data = rCensSp(c(1,4,-1), 2, 3, 0.50, x, coords, "left", 0.05, 0,
               "matern", 3)
data$y[c(10,120)] = NA
data$ci[c(10,120)] = 1
data$ucl[c(10,120)] = Inf

fit2 = SAEM.sclm(y=data$y, x=x, ci=data$ci, lcl=data$lcl, ucl=data$ucl,
                 coords, phi0=2, nugget0=1, type="matern", kappa=3,
                 M=10, pc=0.18)
fit2$tab
plot(fit2)
```

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