Package: BMEmapping (via r-universe)

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Type Package

Title Spatial Interpolation using Bayesian Maximum Entropy (BME)

Version 1.2.2.9000

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Description Provides an accessible and robust implementation of core BME methodologies for spatial prediction. It enables the systematic integration of heterogeneous data sources including both hard data (precise measurements) and soft interval data (bounded or uncertain observations) while incorporating prior knowledge and supporting variogram-based spatial modeling. The BME methodology is described in Christakos (1990) <doi:10.1007/BF00890661>, Serre and Christakos (1999) <doi:10.1007/s004770050029> and Duah (2025, 2026) <doi:10.1016/j.spasta.2026.100974>.

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URL https://github.com/KinspridеDuah/BMEmapping

BugReports https://github.com/KinspridеDuah/BMEmapping/issues

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Contents

`bme_cv` *Leave-one-out cross validation (LOOCV) at hard data locations.*

Description

`bme_cv` performs LOOCV to evaluate the prediction performance of the Bayesian Maximum Entropy (BME) spatial interpolation method using both hard and soft (interval) data. For each hard data location, the function removes the observed value and predicts it using all remaining hard and soft data points. This is repeated for every hard data location. The predictions are either posterior means or posterior modes, depending on the `type` argument.

This function is useful for validating the BME interpolation method and tuning variogram parameters.

Usage

```
bme_cv(data_object, model, nugget, sill, range,
               nsmax = 5, nhmax = 5, n = 50,
               zk_range = extended_range(data_object), type)
```

Arguments

data_object	A list containing the hard and soft data.
model	A string specifying the variogram or covariance model to use (e.g., "exp", "sph", etc.).
nugget	A non-negative numeric value for the nugget effect in the variogram model.
sill	A numeric value representing the sill (total variance) in the variogram model.
range	A positive numeric value for the range (or effective range) parameter of the variogram model.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range.
type	A string indicating the type of BME prediction to compute: either "mean" for the posterior mean or "mode" for the posterior mode.

Value

A data frame containing the coordinates, observed values, BME predictions (posterior mean or mode), posterior variance (if type = "mean"), residuals, and fold indices.

Examples

```
data("utsnowload")
ch <- utsnowload[2:10, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:10, c("hard")]
a <- utsnowload[68:232, c("lower")]
b <- utsnowload[68:232, c("upper")]
data_object <- bme_map(ch, cs, zh, a, b)
bme_cv(data_object,
  model = "exp", nugget = 0.0953, sill = 0.3639,
  range = 1.0787, type = "mean"
)
```

bme_map *Create BMEmapping object*

Description

Function that creates BMEmapping objects; objects that hold all the data information necessary for BME interpolation.

Usage

```
bme_map(ch, cs, zh, a, b)
```

Arguments

ch	A two-column matrix of coordinates for hard data locations.
cs	A two-column matrix of coordinates for soft data locations.
zh	A numeric vector of observed values at the hard data locations.
a	A numeric vector of lower bounds for soft interval data.
b	A numeric vector of upper bounds for soft interval data.

Value

A list containing the input arguments ch, cs, zh, a, and b, with class "BMEmapping".

Examples

```
ch <- matrix(c(1, 2, 3, 4), ncol = 2)
cs <- matrix(c(5, 6, 7, 8), ncol = 2)
zh <- c(10, 20)
a <- c(8, 9)
b <- c(12, 14)
obj <- bme_map(ch, cs, zh, a, b)
class(obj) # "BMEmapping"
```

bme_predict *BME prediction*

Description

bme_predict performs BME spatial interpolation at user-specified estimation locations. It uses both hard data (precise measurements) and soft data (interval or uncertain measurements), along with a specified variogram model, to compute either the posterior mean or mode and associated variance for each location. This function enables spatial prediction in settings where uncertainty in data must be explicitly accounted for, improving estimation accuracy when soft data is available.

Usage

```
bme_predict(x, data_object, model, nugget, sill, range,
                    nsmax = 5, nhmax = 5, n = 50,
                    zk_range = extended_range(data_object), type)
```

Arguments

x	A two-column matrix of spatial coordinates for the estimation locations.
data_object	A list containing the hard and soft data.
model	A string specifying the variogram or covariance model to use (e.g., "exp", "sph", etc.).
nugget	A non-negative numeric value for the nugget effect in the variogram model.
sill	A numeric value representing the sill (total variance) in the variogram model.
range	A positive numeric value for the range (or effective range) parameter of the variogram model.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range.
type	A string indicating the type of BME prediction to compute: either "mean" for the posterior mean or "mode" for the posterior mode.

Value

A data frame with either 3 or 4 columns, depending on the prediction type. The first two columns contain the geographic coordinates. If type = "mean", the third and fourth columns represent the posterior mean and its associated variance, respectively. If type = "mode", only a third column is returned for the posterior mode.

Examples

```
data("utsnowload")
x <- utsnowload[1, c("latitude", "longitude")]
ch <- utsnowload[2:67, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:67, c("hard")]
a <- utsnowload[68:232, c("lower")]
b <- utsnowload[68:232, c("upper")]
data_object <- bme_map(ch, cs, zh, a, b)
```

```
bme_predict(x, data_object,
  model = "exp", nugget = 0.0953,
  sill = 0.3639, range = 1.0787, type = "mean"
)
```

`casnowload` *California Snow Load Data*

Description

A subset of data from the 7964 measurement locations included in the 2020 National Snow Load Study. This data is basically on reliability-targeted snow loads (RTSL) in the state of California.

Usage

```
casnowload
```

Format

A data frame with 346 rows and 8 columns.

STATION Name of the snow measuring station

LATITUDE Latitude coordinate position

LONGITUDE Longitude coordinate position

ELEVATION Elevation of the measring station (measured in meters)

RTSL The hard data RTSL value

LOWER The lower endpoint RTSL

UPPER The upper endpoint RTSL

TYPE Type of snow measurement, WESD is direct and SNWD is indirect measurement. Direct measurements are hard data and have the lower, upper and center values are the same. Indirect measurements have LOWER < RTSL < UPPER.

Source

https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/

plot.BMEmapping *Plot Method for BMEmapping Objects (ggplot2)*

Description

Uses ggplot2 to generate diagnostic or posterior density plots for objects of class "BMEmapping" returned by bme_cv() or prob_zk().

Usage

```
## S3 method for class 'BMEmapping'
plot(x, ...)
```

Arguments

x	An object of class "BMEmapping".
...	Additional arguments (currently unused).

prob_zk *Posterior Density Estimation at a Single Location*

Description

Computes the posterior and plots probability density function (PDF) at a single unobserved spatial location using the Bayesian Maximum Entropy (BME) framework. This function integrates both hard data (precise measurements) and soft data (interval or uncertain observations), together with a specified variogram model, to numerically estimate the posterior density across a range of possible values.

Usage

```
prob_zk(x, data_object, model, nugget, sill, range,
               nsmax = 5, nhmax = 5, n = 50,
               zk_range = extended_range(data_object))
```

Arguments

x	A two-column matrix of spatial coordinates for a single estimation location.
data_object	A list containing the hard and soft data.
model	A string specifying the variogram or covariance model to use (e.g., "exp", "sph", etc.).
nugget	A non-negative numeric value for the nugget effect in the variogram model.
sill	A numeric value representing the sill (total variance) in the variogram model.

range	A positive numeric value for the range (or effective range) parameter of the variogram model.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range

Value

A data frame with two columns: zk_i (assumed zk values) and prob_zk_i (corresponding posterior densities).

Examples

```
data("utsnowload")
x <- utsnowload[1, c("latitude", "longitude")]
ch <- utsnowload[2:67, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:67, "hard"]
a <- utsnowload[68:232, "lower"]
b <- utsnowload[68:232, "upper"]
data_object <- bme_map(ch, cs, zh, a, b)
prob_zk(x, data_object,
  model = "exp",
  nugget = 0.0953, sill = 0.3639, range = 1.0787
)
```

---

q_bme_cv *Leave-one-out cross validation (LOOCV) at hard data locations using the random quantile approach.*

Description

q_bme_cv performs LOOCV to evaluate the prediction performance of the Bayesian Maximum Entropy (BME) spatial interpolation using the random quantile approach. For each hard data location, the function removes the observed value and predicts it using all remaining hard and soft data points. This is repeated for every hard data location. The predictions are either posterior means or posterior modes, depending on the type argument.

This function is useful for validating the BME interpolation method and tuning variogram parameters.

Usage

```
q_bme_cv(data_object, nsmax = 5, nhmax = 5, n = 50, nq = 3,
              zk_range = extended_range(data_object), type)
```

Arguments

data_object	A list containing the hard and soft data.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
nq	A positive numeric value for the number of quantile levels (default is 3).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range.
type	A string indicating the type of BME prediction to compute: either "mean" for the posterior mean or "mode" for the posterior mode.

Value

A data frame containing the coordinates, observed values, BME predictions (posterior mean or mode), posterior variance (if type = "mean"), residuals, and fold indices.

Examples

```
data("utsnowload")
ch <- utsnowload[2:10, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:10, c("hard")]
a <- utsnowload[68:232, c("lower")]
b <- utsnowload[68:232, c("upper")]
data_object <- bme_map(ch, cs, zh, a, b)
q_bme_cv(data_object, nq = 3, type = "mean")
```

---

q_bme_predict *BME prediction using the random quantile approach*

Description

q_bme_predict performs BME spatial interpolation at user-specified estimation locations. It uses both hard data (precise measurements) and soft data (interval or uncertain measurements), along with a specified variogram model, to compute either the posterior mean or mode and associated variance for each location. This function enables spatial prediction in settings where uncertainty in data must be explicitly accounted for, improving estimation accuracy when soft data is available.

Usage

```
q_bme_predict(x, data_object, nsmax = 5, nhmax = 5, n = 50, nq = 3,
                   zk_range = extended_range(data_object), type)
```

Arguments

x	A two-column matrix of spatial coordinates for the estimation locations.
data_object	A list containing the hard and soft data.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
nq	A positive numeric value for the number of quantile levels (default is 3).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range.
type	A string indicating the type of BME prediction to compute: either "mean" for the posterior mean or "mode" for the posterior mode.

Value

A data frame with either 3 or 4 columns, depending on the prediction type. The first two columns contain the geographic coordinates. If type = "mean", the third and fourth columns represent the posterior mean and its associated variance, respectively. If type = "mode", only a third column is returned for the posterior mode.

Examples

```
data("utsnowload")
x <- utsnowload[1, c("latitude", "longitude")]
ch <- utsnowload[2:67, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:67, c("hard")]
a <- utsnowload[68:232, c("lower")]
b <- utsnowload[68:232, c("upper")]
```

```
data_object <- bme_map(ch, cs, zh, a, b)
q_bme_predict(x, data_object, type = "mean")
```

---

q_prob_zk *Posterior Density Estimation at a Single Location*

Description

Computes the posterior and plots probability density function (PDF) at a single unobserved spatial location using the Bayesian Maximum Entropy (BME) framework. This function integrates both hard data (precise measurements) and soft data (interval or uncertain observations), together with a specified variogram model, to numerically estimate the posterior density across a range of possible values.

Usage

```
q_prob_zk(x, data_object, nsmax = 5, nhmax = 5, n = 50, nq = 3,
                  zk_range = extended_range(data_object))
```

Arguments

x	A two-column matrix of spatial coordinates for a single estimation location.
data_object	A list containing the hard and soft data.
nsmax	An integer specifying the maximum number of nearby soft data points to include for estimation (default is 5).
nhmax	An integer specifying the maximum number of nearby hard data points to include for estimation (default is 5).
n	An integer indicating the number of points at which to evaluate the posterior density over zk_range (default is 50).
nq	An integer indicating the number of quantile levels (default is 3).
zk_range	A numeric vector specifying the range over which to evaluate the unobserved value at the estimation location (zk). Although zk is unknown, it is assumed to lie within a range similar to the observed data (zh, a, and b). It is advisable to explore the posterior distribution at a few locations using prob_zk() before finalizing this range

Value

A data frame with two columns: zk_i (assumed zk values) and prob_zk_i (corresponding posterior densities).

Examples

```
data("utsnowload")
x <- utsnowload[1, c("latitude", "longitude")]
ch <- utsnowload[2:67, c("latitude", "longitude")]
cs <- utsnowload[68:232, c("latitude", "longitude")]
zh <- utsnowload[2:67, "hard"]
a <- utsnowload[68:232, "lower"]
b <- utsnowload[68:232, "upper"]
data_object <- bme_map(ch, cs, zh, a, b)
q_prob_zk(x, data_object)
```

---

summary.BMEmapping *Summary Method for BME Cross-Validation Results*

Description

Provides a concise summary of LOOCV performance for BME predictions at hard data locations. Computes standard residual-based accuracy metrics, including Mean Error (ME), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE).

Usage

```
## S3 method for class 'BMEmapping'
summary(object, ...)
```

Arguments

`object`	An object of class `"bme_cv"`, typically returned by a BME cross-validation function. Must contain a numeric vector named `residual`.
`...`	Additional arguments passed to `summary()`.

Value

A data frame containing three columns:

`ME` Mean Error (average residual).

`MAE` Mean Absolute Error.

`RMSE` Root Mean Squared Error.

`utahsnowload` *A detrended reliability-targeted design ground snow loads in Utah*

Description

This dataset contains detrended reliability-targeted design ground snow load measurements from 232 locations in state of Utah. Of these, 65 sites report precise measurements, treated as hard data, while the remaining 167 sites report imprecise measurements, represented as interval (soft) data. The dataset is structured such that the first 67 rows contain hard (point) measurements, and the remaining rows represent soft data using lower and upper interval bounds. For a detailed explanation of the dataset and its use, refer to the related version described in Duah et al. (2025) doi:10.1016/j.spasta.2025.100894

Usage

```
utsnowload
```

Format

A data frame with 232 rows and 5 variables:

latitude Latitude coordinate position

longitude Longitude coordinate position

hard The hard data value

lower The lower endpoint of the soft-interval

upper The upper endpoint of the soft-interval

Source

doi:10.1016/j.spasta.2025.100894

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