Package ‘ETAS’

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Title Modeling earthquake data using Epidemic Type Aftershock Sequence model

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Depends R (>= 2.10), spatstat, methods

Suggests maptools, scatterplot3d

Description A package for fitting the ETAS model to earthquake catalogoues ETAS model is a spatio-temporal marked point process model and a special case of the Hawcks process

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R topics documented:

`check.temporal` *Check the temporal coordinate of a point pattern*

Description

A function to check the temporal coordinate of a spatio-temporal point pattern to be in ascending order.

Usage

```
check.temporal(X)
```

Arguments

`X`	Marked spatio-temporal point pattern (object of class "ppx").

Details

The function produces a message (character string) indicating whether the temporal coordinate of the point pattern is in asceding order or not.

Value

A character string.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir> http://www.razi.ac.ir/jalilian/

See Also

ppx.

Examples

```
check.temporal(iran.quakes)

check.temporal(jap.quakes)
```

date2day *Convert date-time data to numeric data in days*

Description

A function to convert date-time data to days with respect to a date-time origin.

Usage

```
date2day(dates, start, tz="", ...)
```

Arguments

`dates`	A date-time or date object. Typically, it is a character vector containing date-time information.
`start`	A date-time or date object. Determines the origin of the conversion.
`tz`	Optional. Timezone specification to be used for the conversion.
`...`	Arguments to be passed to `as.POSIXlt`.

Details

The arguments `dates` and `start` must be of appropriate format to be passed to `as.POSIXlt` function.

Value

A numeric vector of the same length as `dates`.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir> http://www.razi.ac.ir/jalilian/

See Also

`as.POSIXlt` and `difftime` for appropriate format of the data to be converted.

Examples

```
# date-time data of Iran's earthquakes between 1902/0/01 and 2012/06/01
dt <- iran.quakes$data$date
# origin of the conversion
start <- "1902/01/01 00:00:00"
# time in days since 1902-01-01 (UTC)
date2day(dt, start, tz="GMT")
```

etas *Fit the space-time ETAS model to data*

Description

A function to fit the space time epidemic type aftershock sequence (ETAS) model to a catalog (point pattern) of earthquakes and perform a stochastic declustering method.

Usage

```
etas(X, win, tperiod, m0, param0, bwd = NULL, nnp = 5, bwm = 0.05,
     verbose = TRUE, plot.it = TRUE, no.itr = 11)
```

Arguments

`X`	Marked spatio-temporal point pattern (object of class `"ppx"`) representing time, spatial location, magnitude and ... of earthquakes.
`win`	Target geographical region of study (object of class `"owin"`). Events outside this region are treated as complementary events in the log-likelihood.
`tperiod`	Time period of quakes. A numeric vector of size 2: (tstart, tlength). `tstart` is the starting point of time target interval and `tlength` is the total length of time period.
`m0`	Minimum magnitude threshold. A positive numeric value.
`param0`	Initial guess for model parameters. A numeric vector of appropriate length (currently 8).
`bwd`	Optional. Bandwidths for smoothness and integration on the geographical region `win`. A numeric vector which has the length of the number of events. If not supplied, the following arguments `nnp` and `bwm` determine bandwidths.
`nnp`	Number of nearest neighbors for bandwidth calculations. An integer.
`bwm`	Minimum bandwidth. A positive numeric value.
`verbose`	Logical flag indicating whether to print progress reports.
`plot.it`	Logical flag indicating whether plot probabilities of each event being a background even on a map.
`no.itr`	An integer indicating the number of iterations for convergence of the iterative approach of declustering algorithm. See details.

Details

Ogata (1988) introduced the epidemic type aftershock sequence (ETAS) model based on Gutenberg-Richter law and modified Omori law. In its space-time representation (Ogata, 1998), the ETAS model is a temporal marked point process model, and a special case of marked Hawks process, with conditional intensity function

$$\lambda(t, x, y|H_t) = \mu(x, y) + \sum_{t_i<t} k(m_i)g(t - t_i)f(x - x_i, y - y_i|m_i)$$

where

H_t**:** is the observational history up to time t, but not including t; that is

$$H_t = \{(t_i, x_i, y_i, m_i) : t_i < t\}$$

$\mu(x, y)$**:** is the background intensity. Currently it is assumed to take the semi-parametric form

$$\mu(x, y) = \mu u(x, y)$$

where μ is an unknown constant and $u(x, y)$ is an unknown function.

$k(m)$**:** is the expected number of events triggered from an event of magnitude m given by

$$k(m) = A \exp(\alpha(m - m_0))$$

$g(t)$**:** is the p.d.f of the occurrence times of the triggered events, taking the form

$$g(t) = \frac{p-1}{c}(1 + \frac{t}{c})^{-p}$$

$f(x, y|m)$**:** is the p.d.f of the locations of the triggered events, considered to be either the long tail inverse power density

$$f(x, y|m) = \frac{q-1}{\pi\sigma(m))}(1 + \frac{x^2 + y^2}{\sigma(m)})^{-q}$$

or the light tail Gaussian density (currently not implemented)

$$f(x, y|m) = \frac{1}{2\pi\sigma(m)} \exp(-\frac{x^2 + y^2}{2\sigma(m)})$$

with

$$\sigma(m) = D \exp(\gamma(m - m_0))$$

The ETAS models classify seismicity into two components, background seismicity $\mu(x, y)$ and clustering seismicity $\lambda(t, x, y|H_t) - \mu(x, y)$, where each earthquake event, whether it is a background event or generated by another event, produces its own offspring according to the branching rules controlled by $k(m)$, $g(m)$ and $f(x, y|m)$.

Background seismicity rate $u(x, y)$ and the model parameters

$$\theta = (\mu, A, c, \alpha, p, D, q, \gamma)$$

are estimated simultaneously using an iterative approach proposed in Zhuang et al. (2002). First, for an initial $u_0(x, y)$, the parameter vector θ is estimated by maximizing the log-likelihood function

$$l(\theta) = \sum_i \lambda(t_i, x_i, y_i|H_{t_i}) - \int \lambda(t, x, y|H_t) dxdydt.$$

Then the procedure calculates the probability of being a background event for each event in the catalog by

$$\phi_i = \frac{\mu(x_i, y_i)}{\lambda(t_i, x_i, y_i|H_{t_i})}.$$

Using these probabilities and kernel smoothing method with Gaussian kernel and appropriate choice of bandwidth (determined by `bwd` or `nnp` and `bwm` arguments), the background rate $u_0(x, y)$ is updated. These steps are repeated enough times (determined by `no.itr` argument) such that the results converge.

The procedure is a `C` port of the original `Fortran` code by Ogata, Zhunang and their colleagues.

Value

A list with components

param: The ML estimates of model parameters.

bk: An estimate of the $u(x, y)$.

pb: The probabilities of being background event.

opt: The results of optimization: the value of the log-likelihood function at the optimum point, its gradient at the optimum point and AIC of the model.

rates: Pixel images of the estimated total intensity, background intensity, clustering intensity and conditional intensity.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir> http://www.razi.ac.ir/jalilian/

References

Zhuang, J., Ogata, Y. and Vere-Jones, D. (2005). Diagnostic analysis of space-time branching processes for earthquakes. Lecture Note in Statistics: *Case Studies in Spatial Point Process Models* (Baddeley, A., Gregori, P., Mateu, J., Stoica, R. and Stoyan, D.), Springer-Verlag, New York, **185**, 276–292.

Zhuang, J., Ogata, Y. and Vere-Jones, D. (2002). Stochastic declustering of space-time earthquake occurrences. *Journal of the American Statistical Association*, **97**, 369–380.

Ogata, Y. (1998). Space-time point-process models for earthquake occurrences. *Annals of the Institute of Statistical Mathematics*, **50**, 379–402.

Ogata, Y. (1988). Statistical models for earthquake occurrences and residual analysis for point processes. *Journal of American Statistical Association*, **83**, 9–27.

See Also

ppx and owin for constructing data.

etasfit.

Examples

```
  # fitting the ETAS model to an Iranian catalog
  ## Not run:
  plot(iran.quakes)

## End(Not run)
  # specifiying the geographical region
  win <- owin(c(41, 66), c(24, 42))
  ## Not run:
  plot(iran.quakes$data[, 2:3])
  plot(win, add=TRUE)

## End(Not run)
  # projecting log-lat coordinates into flat map coordinates
```

```
  proj <- long2flat(iran.quakes, win)
  # specifying time period
  tperiod <- c(25000, 40329)
  # initial parameters values
  param01 <- c(0.4339678,
   0.1988628,
   0.0345206,
   1.6290137,
   1.1286776,
   0.0072539,
   2.1705884,
   0.5706402)
  ## Not run:
  res <- etas(proj$X, proj$win, tperiod, m0=4.5, param0=param01, no.itr=1)

## End(Not run)



  # fitting the ETAS model to a Japanese catalog
  ## Not run:
  plot(jap.quakes)

## End(Not run)
  # specifiying the geographical region
  jwin <- owin(poly=list(x=c(134.0, 137.9, 143.1, 144.9,
                       147.8, 137.8, 137.4, 135.1, 130.6),
                        y=c(31.9, 33.0, 33.2, 35.2, 41.3,
                            44.2, 40.2, 38.0, 35.4)))
  ## Not run:
  plot(jap.quakes$data[, 2:3])
  plot(jwin, add=TRUE)

## End(Not run)
  # projecting log-lat coordinates into flat map coordinates
  proj <- long2flat(jap.quakes, jwin)
  # specifying time period
  tperiod <- c(10000, 23376)
  # initial parameters values
  param00 <- c(0.592844590,
   0.204288231,
   0.022692883,
   1.495169224,
   1.109752319,
   0.001175925,
   1.860044210,
   1.041549634)
  ## Not run:
  res <- etas(proj$X, proj$win, tperiod, m0=4.5, param0=param00, no.itr=11)

## End(Not run)
```

etas.object *Class of Fitted ETAS Models*

Description

A class `etas` to represent a fitted ETAS model. The output of `etas`.

Details

An object of class `etas` represents an ETAS model that has been fitted to a spatio-temporal point pattern (catalog) of earthquakes. It is the output of the model fitter, `etas`.

The class `etas` has methods for the following standard generic functions:

generic	method	description
`print`	`print.etas`	print details

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir> http://www.razi.ac.ir/jalilian/

See Also

`etas`,

Examples

```
 win <- owin(c(41, 66), c(24, 42))
 proj <- long2flat(iran.quakes, win)
 param01 <- c(0.4339678,
  0.1988628,
  0.0345206,
  1.6290137,
  1.1286776,
  0.0072539,
  2.1705884,
  0.5706402)
## Not run:
 res <- etas(proj$X, proj$win, tperiod, m0=4.5, param0=param01, no.itr=1)
 res

## End(Not run)
```

`iran.quakes`	*20th century earthquakes of Iran*

Description

A point pattern giving occurrence time (in days), location of epicenter (longitude and latitude both in decimal degrees) and magnitude of shalow earthquakes (depth < 100 km) occurred since 1902-01-01 till 2012-06-01 in Iran and its vicinity. Earthquakes with magnitude less than 4.5 have been excluded from data.

Usage

```
data(iran.quakes)
```

Format

An object of class `"ppx"` representing informations about

- data

`time`	Occurrence time (days)
`long`	Longitude of epicenter (degree)
`lat`	Latitude of epicenter (degree)
`mag`	Magnitude (different scales)
`mag.type`	Magnitude type
`depth`	Depth (km)
`ref`	Reference
`date`	Actual date and time (UTC)

- and domian of data

`time domain`	[0, 15492] : from 1970-01-01 (time origin 0) to 2012-06-01 (15492)
`spatial domain`	[41, 67] * [20.5, 44.5]
`mark domain`	[4.5, `Inf`)

Notes

more points about the data, their accuracy and ....

Source

International Institute of Earthquake Engineering and Seismology (IIEES): www.iiees.ac.ir/

References

Jalilian, A. (2012). Modeling Earthquakes of Iran.

`jap.quakes` *Earthquakes of Japan*

Description

A point pattern giving occurrence time (in days), location of epicenter (longitude and latitude both in decimal degrees) and magnitude of shalow earthquakes (depth < 100 km) occurred since 1926-01-08 till 2008-01-01 in Japan and its vicinity. Earthquakes with magnitude less than 4.5 have been excluded from data.

Usage

```
data(jap.quakes)
```

Format

An object of class `"ppx"` representing informations about

- data

`time`	Occurrence time (days)
`long`	Longitude of epicenter (degree)
`lat`	Latitude of epicenter (degree)
`mag`	Magnitude (different scales)
`depth`	Depth (km)
`date`	Actual date (local time)

- and domian of data

`time domain`	[0, 15492] : from 1926-01-08 (time origin 0) to 2007-12-29 (29943)
`spatial domain`	[128, 145] x [27, 45]
`mark domain`	[4.5, Inf)

Notes

more points about the data, their accuracy and ....

Source

(?)

References

Zhuang and Ogata (?)

lambda *Clustering Part of Conditional Intensity Function of the ETAS Model*

Description

A function to compute the clustering part of the conditional intensity function of the ETAS model at specified time and location.

Usage

```
lambda(t, x, y, param, X, m0)
```

Arguments

`t`	A numeric value. The time that the conditional intensity is to be computed at.
`x`	A numeric value. The x-coordinate of the location that the conditional intensity is to be computed at.
`y`	A numeric value. The y-coordinate of the location that the conditional intensity is to be computed at.
`param`	Vector of model paramters.
`X`	Marked spatio-temporal point pattern (object of class `ppx`) representing time, sptial location, magnitude and ... of earthquakes.
`m0`	Minimum magnitude threshold.

Details

For a given t, x and y, this function computes

$$\sum_{t_i<t} k(m_i)g(t-t_i)f(x-x_i, y-y_i|m_i).$$

Value

A numeric value.

Author(s)

Abdollah Jalilian `<jalilian@razi.ac.ir>` http://www.razi.ac.ir/jalilian/

References

Zhuang, J., Ogata, Y. and Vere-Jones, D. (2005). Diagnostic analysis of space-time branching processes for earthquakes. Lecture Note in Statistics: *Case Studies in Spatial Point Process Models* (Baddeley, A., Gregori, P., Mateu, J., Stoica, R. and Stoyan, D.), Springer-Verlag, New York, **185**, 276–292.

Zhuang, J., Ogata, Y. and Vere-Jones, D. (2002). Stochastic declustering of space-time earthquake occurrences. *Journal of the American Statistical Association*, **97**, 369–380.

See Also

etas

ppx

Examples

```
param00 <- c(0.592844590,
  0.204288231,
  0.022692883,
  1.495169224,
  1.109752319,
  0.001175925,
  1.860044210,
  1.041549634)

win <- owin(c(41, 66), c(24, 42))
proj <- long2flat(iran.quakes, win)
lambda(50435, 40.12, 34.5, param00, proj$X, 4.5)
```

---

long2flat *Project longitude-latitude coordinates to flat map coordinates*

Description

A function to adjust the longitude of coordinates of a set of points in a geographical region on earth in order to have a flat map coordinates.

Usage

```
long2flat(X, win)
```

Arguments

`X`	Marked spatio-temporal point pattern (object of class `ppx`).
`win`	Target geographical region of study (object of class `owin`).

Details

The algorithm does not change the latitude of points but adjust the longitude of points with respect to the centroid of the target geographical region `win` in order to get coordinates on a flat surface.

Value

A list with components

X: The same point pattern as the input argument `X` except that the longitude coordinates of its points are adjusted.

win: The same window as the input argument `win` except that the longitude coordinates of its vertexes are adjusted.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir> http://www.razi.ac.ir/jalilian/

See Also

ppx

owin

Examples

```
  # specifiying the geographical region
  win <- owin(c(41, 66), c(24, 42))
  ## Not run:
  plot(iran.quakes$data[, 2:3])
  plot(win, add=TRUE)

## End(Not run)
  # projecting log-lat coordinates into flat map coordinates
  proj <- long2flat(iran.quakes, win)
  ## Not run:
  plot(proj$X$data[, 2:3])
  plot(proj$win, add=TRUE)

## End(Not run)

  # specifiying the geographical region
  jwin <- owin(poly=list(x=c(134.0, 137.9, 143.1, 144.9,
                      147.8, 137.8, 137.4, 135.1, 130.6),
                       y=c(31.9, 33.0, 33.2, 35.2, 41.3,
                           44.2, 40.2, 38.0, 35.4)))
  ## Not run:
  plot(jap.quakes$data[, 2:3])
  plot(jwin, add=TRUE)

## End(Not run)
  # projecting log-lat coordinates into flat map coordinates
  proj <- long2flat(jap.quakes, jwin)
  # specifying time period
  ## Not run:
  plot(proj$X$data[, 2:3])
  plot(proj$win, add=TRUE)

## End(Not run)
```

---

print.etas *Print a Fitted ETAS Model*

Description

Default print method for a fitted ETAS model.

Usage

```
 ## S3 method for class 'etas'
print(x,...)
```

Arguments

x	A fitted ETAS model, obtained from the model-fitting algorithm `etas`. An object of class `"etas"`.
...	Ignored.

Details

This is the `print` method for the class `"etas"`. It prints information about the fitted model in a sensible format.

Value

None.

Author(s)

Abdollah Jalilian `<jalilian@razi.ac.ir>` `http://www.razi.ac.ir/jalilian/`

See Also

`etas` for fitting an ETAS model.

Examples

```
  win <- owin(c(41, 66), c(24, 42))
  proj <- long2flat(iran.quakes, win)
  param01 <- c(0.4339678,
   0.1988628,
   0.0345206,
   1.6290137,
   1.1286776,
   0.0072539,
   2.1705884,
   0.5706402)
 ## Not run:
  res <- etas(proj$X, proj$win, tperiod, m0=4.5, param0=param01, no.itr=1)
  res

## End(Not run)
```

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