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Analysis of forest fires in Comunidad Valenciana (Spain) using a spatial statistics methodology

Pablo Gregori, Pablo Juan, Jorge Mateu and Fuensanta Saura

Department of Mathematics. UJI (Castellón, Spain)

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Overview

$$\left\{ \begin{array}{l} Forest\ fires \\ \\ Risk\ index\ of\ forest\ fires \end{array} \right\} \rightarrow Goodness\ of\ the\ risk\ index$$

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2. Kinds of risk index

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Region of interest

Comunidad Valenciana

REASONS:

- Burned surface

  1976-1992: 434000 Ha., $11{,}3\,\%$ of total burned area

  1991-2000: 253741 Ha.,$15{,}8\,\%$ of total burned area

- Location (winds)
- Natural resources
- Etc.

Forest fires in Comunidad Valenciana (Spain)

Data base provided by Consejeria de Territorio y Vivienda: 1968-2002

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- Time of detection
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- Town or county

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- Time of detection
- Burned surface
- Town or county
- Fire extinction elements

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Forest fires in Comunidad Valenciana (Spain)

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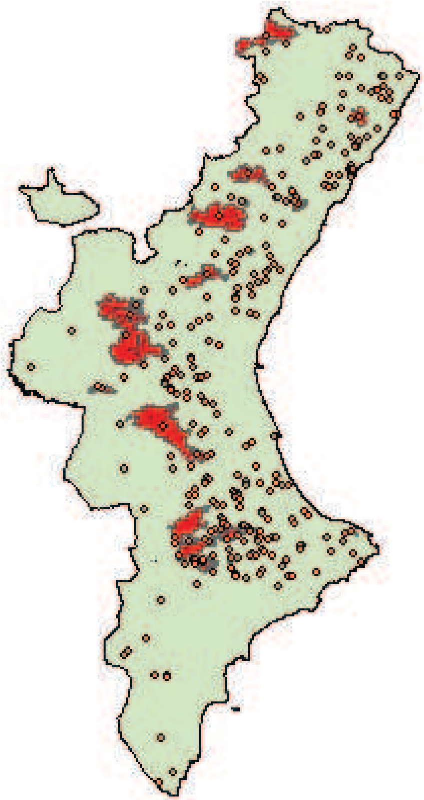
- Time of detection
- Burned surface
- Town or county
- Fire extinction elements
- Time of extinction
- Others...

Forest fires in Comunidad Valenciana (Spain)



Forest fires registered in Comunidad Valenciana during 1994.

Risk index of forest fire (1): NIM

Sequential procedure (3 Tables):

1)Table 1:

$$\left\{ \begin{array}{c} -Relative\ moisture \\ -Air\ temperature \\ -Month \end{array} \right\} \rightarrow Relative\ moisture\ for\ fuel$$

2)Table 2:

$$\left\{ \begin{array}{c} -Relative\ moisture\ for\ fuel \\ -Air\ temperature \end{array} \right\} \rightarrow Ignition\ probability$$

Risk index of forest fire (1): NIM

Sequential procedure:

3)Table 3:

$$\left\{ \begin{array}{c} -Ignition\ probability \\ -Wind\ speed \\ -Kind\ of\ wind \end{array} \right\} \rightarrow Risk\ index : 0, 1, 2, 3$$

Risk index of forest fire (2): Territorial NIM

Measured variables in different meteorological stations :

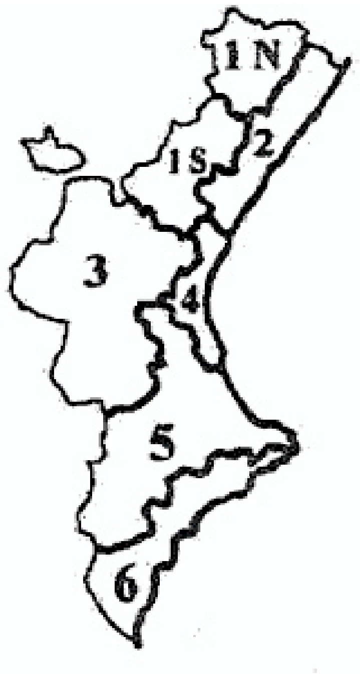
$$\left\{ \begin{array}{c} -Maximum\ gust\ of\ wind \\ -Minimum\ of\ relative\ moisture \\ -Maximum\ temperature \\ -Kind\ of\ wind \end{array} \right\} \rightarrow Burned\ surface/day$$

Modifications:

-Number of the day in the year
-Water resources in soil
-Spatial region of 6
-Special consideration during holidays

Index I: 1,2,3

Risk index of forest fire (2): Territorial NIM



Distribution of zones for Territorial NIM forest fire risk.

Risk index of forest fire (3): LATUV

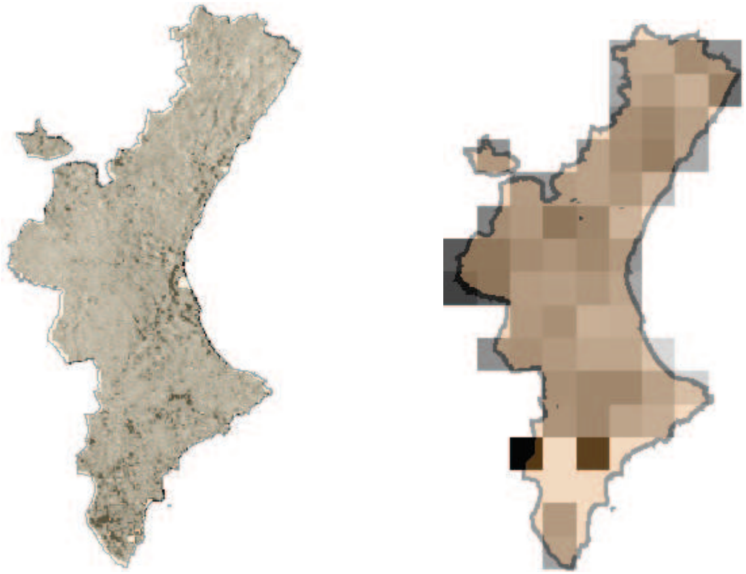
Index of danger of a fire under the hypothesis it happened

$$\left\{ \begin{array}{l} NDVI \ (Normalized \\ difference \ vegetation \ index) \end{array} \right\} \rightarrow Normalized \ residual$$

$$\left\{ \begin{array}{l} NDVI \\ Surface \ Temperature \end{array} \right\} \rightarrow Meteorological \ indicator$$

$$\left\{ \begin{array}{l} -Normalized \ residual : \ 1x1 \ km^2 \\ -Meteorological \ indicator : \ 20x20km^2 \end{array} \right\} \rightarrow Risk \ Index : 0, 1, 2, 3, 4$$

Risk index of forest fire (4): LATUV

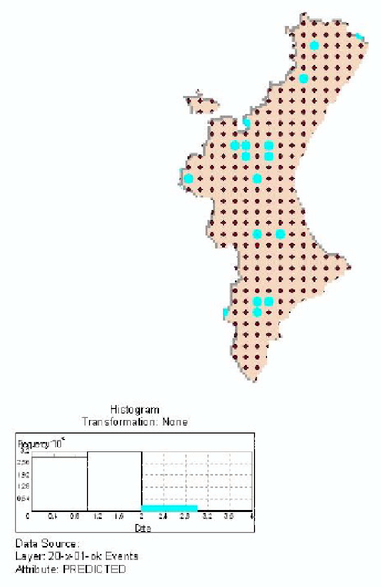


Normalized residual and meteorological indicator for 20/07/2001

Risk index of forest fire (5): LATUV

Grid of size 19x34

Daily values during period 2000-2001



Risk index for 20/07/2000 when it is bigger than 2

Missing data for 2000-2001

◇ Missing days in 2000:

January-May: **empty**
June: **4**
July: **12**
August: **24**
September:**25**
October-December: **empty**

◇ Missing days in 2001:

January-April: **empty**
May: **20**
June: **3**
July: **3**
August: **2**
September:**6**
October-December: **empty**

Ordinary kriging

- Missing cells for a particular day: Spatial Ordinary Kriging (or Spatial indicator kriging)

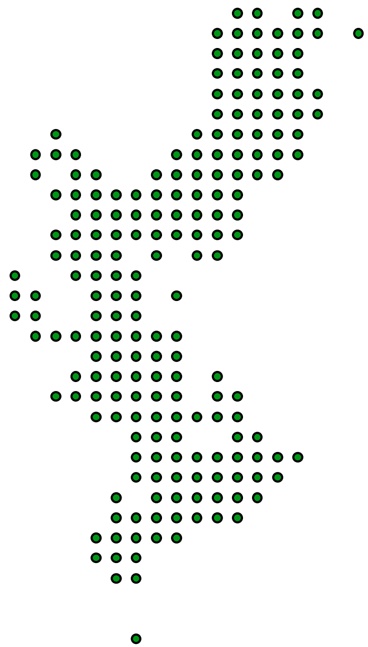
◇$Y(c)$: value of the risk index at cell c
◇$\{Y(c_{i_1}), Y(c_{i_2}), \ldots, Y(c_{i_k})\}$: known values of the risk index at a particular day
◇Kriging predictor for $Y(c)$:

$$Y^*(c) = \sum_{j=1}^{k} \lambda_j Y(c_{i_j})$$

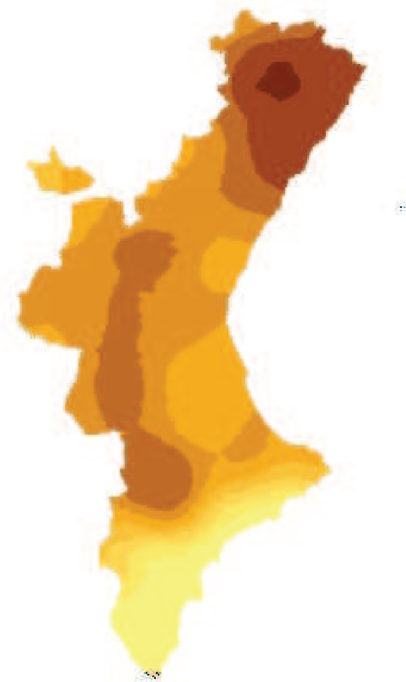
where the coefficients $\{\lambda_j\}_{j=1}^{k}$ must be determined
Note: predictions are not integer values now

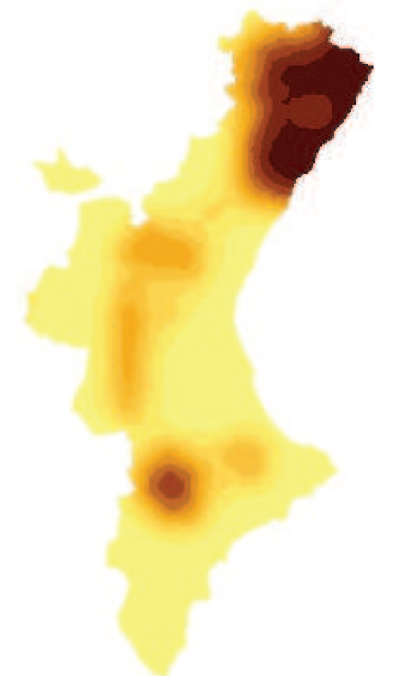
Example of spatial kriging

Day: 07-07-01



Original risk index





Ordinary and Indicator kriging

Spatial-Temporal kriging (1)

- Missing full days:

Spatial-Temporal kriging (1)

- Missing full days:

▲ Data: two previous days

Spatial-Temporal kriging (1)

- Missing full days:

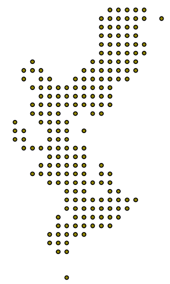
- ▲ Data: two previous days
- ▲ Remove the mean value

Spatial-Temporal kriging (1)

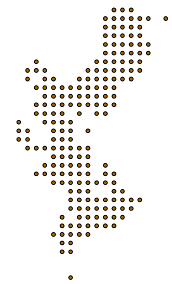
- Missing full days:

- ▲ Data: two previous days
- ▲ Remove the mean value
- ▲ Spatial temporal kriging for gaussian fields over small squared matrices

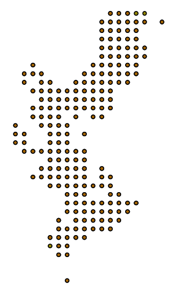
Example of spatial-temporal missing data



Original cells (07-06-00)



Original cells (08-06-00)



Common cells

Spatial-Temporal kriging (2)

-Covariance model chosen by minimizing BIC: (Cressie and Huang, 1999):

$$C(\boldsymbol{h}, u \mid \boldsymbol{\theta}) = \begin{cases} \dfrac{\sigma_Y^2 (2\beta^{d/2})}{(a^2u^2+1)^{\nu}(a^2u^2+\beta)^{d/2}\Gamma(\nu)} \left\{ \dfrac{b}{2} \left(\dfrac{a^2u^2+1}{a^2u^2+\beta} \right)^{1/2} \|\boldsymbol{h}\| \right\}^{\nu} & \\ \times K_{\nu} \left(b \left(\dfrac{a^2u^2+1}{a^2u^2+\beta} \right)^{1/2} \|\boldsymbol{h}\| \right); & \text{if } \|\boldsymbol{h}\| > 0, \\ \dfrac{\sigma_Y^2 \beta^{d/2}}{(a^2u^2+1)^{\nu}(a^2u^2+\beta)^{d/2}}; & \text{if } \|\boldsymbol{h}\| = 0, \end{cases}$$

where $\boldsymbol{\theta} \equiv (a, b, \beta, \nu, \sigma_Y^2, \sigma_\varepsilon^2)^t$, K_ν is the modified Bessel function of the second kind of order ν, $a \geq 0$ is the scaling parameter of time, $b \geq 0$ is the scaling parameter of space, $\beta > 0$ is a space-time interaction parameter, $\nu > 0$ is a smoothness parameter, and $\sigma_Y^2 = C(\mathbf{0}, 0) > 0$.

Spatial-Temporal kriging (3)

and (Gneiting, 2002):

$$C(\boldsymbol{h}, u \mid \boldsymbol{\theta}) = \begin{cases} \dfrac{\sigma_Y^2}{2^{\nu-1}\Gamma(\nu)(a|u|^{2\alpha}+1)^{\delta+\beta}} \left(\dfrac{b\|\boldsymbol{h}\|}{(a|u|^{2\alpha}+1)^{\beta/2}} \right)^{\nu} \\ \times K_\nu\left(\dfrac{b\|\boldsymbol{h}\|}{(a|u|^{2\alpha}+1)^{\beta/2}} \right); & \text{if } \|\boldsymbol{h}\| > 0 \,, \\ \dfrac{\sigma_Y^2}{(a|u|^{2\alpha}+1)^{\delta+\beta}} \,; & \text{if } \|\boldsymbol{h}\| = 0 \,, \end{cases}$$

where $\boldsymbol{\theta} \equiv (a, b, \alpha, \beta, \nu, \delta, \sigma_Y^2, \sigma_\varepsilon^2)^t$, $a > 0$ and $b > 0$ are scaling parameters of time and space, respectively, $\alpha \in (0, 1]$ is the smoothness parameter of time, $\nu > 0$ is the smoothness parameter of space, $\beta \in [0, 1]$, $\delta \geq 0$, and $\sigma_Y^2 > 0$.

Spatial-Temporal kriging (4)

-Add the spatial-temporal kriging to the mean values

-Round to 0,1,2,3,4

-Spatial Ordinary Kriging

Filling data for remaining days

-Mean value of existing index for days were no fire happened

-Mean value of existing index for days were a fire happened

Particularity: weight them depending on the month each day belongs to (0.5 for January-April and October-December, 1 for May-September)

Use of Intensity function

Methodology developed by R. Peng, F. P. Schoenberg and J. Woods

◇Spatial-temporal point process in $\mathbb{R}^+ \times D$, $D \subset \mathbb{R}^2$
◇$N(T \times S)$ denotes the number of events in a Borel temporal set T and Borel spatial one S

◇The conditional intensity function is defined in $(t, x, y) \in \mathbb{R}^+ \times D$, as

$$\lambda(t,x,y) = \lim_{\Delta t, \Delta x, \Delta y} \frac{E[N((t,t+\Delta t) \times (x,x+\Delta x) \times (y,y+\Delta y))|F_t]}{\Delta t \Delta x \Delta y}$$

when it exists. F_t is a filtration.

Use of Intensity function

Aim: Use the conditional intensity function to study the goodness of a particular forest fire risk index

How? Considering different models involving the risk index and studying if they agree properly with the data

Models

$$\lambda_1(t,x,y) = \nu$$

$$\lambda_2(t,x,y) = \nu m(x,y)$$

$$\lambda_3(t,x,y) = \alpha S(t)$$

$$\lambda_4(t,x,y) = \alpha\nu m(x,y)S(t)$$

$$\lambda_5(t,x,y) = \nu m(x,y) + \alpha S(t)$$

$$\lambda_6(t,x,y) = \beta I(t,x,y)$$

$$\lambda_7(t,x,y) = \alpha\nu\beta m(x,y)S(t)I(t,x,y)$$

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Parameters

where

$$m(x,y) = \frac{1}{N}\sum_{i=1}^{N} \frac{1}{\phi_x \phi_y} K(\frac{x - x_i}{\phi_x}) K(\frac{y - y_i}{\phi_y})$$

$$S(t) = \frac{1}{N}\sum_{i=1}^{N} \frac{1}{\phi_t} K(\frac{t - t_i}{\phi_t})$$

being $\{(t_i, x_i, y_i)\}_{i=1}^{N}$ the events of the process, K a gaussian one-dimensional kernel, the parameters are $\nu, \alpha, \beta, \phi_t, \phi_x, \phi_y > 0$ and I denotes the value of the risk index.

Fitting

Use of the log-likelihood function

$$l(\theta) = \sum_{i=1}^{N} log\lambda(t_i, x_i, y_i; \theta) - \int_{T_0}^{T_1} \int_D \lambda(t, x, y; \theta) d(x, y) dt$$

where $\lambda(t_i, x_i, y_i; \theta)$ denotes the value of the conditional intensity function for the set of parameters represented by θ and $[T_0, T_1]$ is the temporal set.

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Goodness of the model

-Akaike's Information Criteria value

-Residual analysis:carrying out a thinning of the original spatial-temporal pattern with a fixed number of points $0 < K < N$

Probability of each point to be deleted:

$$p_i = 1 - \frac{1/\lambda(t_i, x_i, y_i; \theta)}{\sum_{k=1}^{N} 1/\lambda(t_k, x_k, y_k; \theta)}$$

θ would be replaced by the obtained fitted parameters.
The fitted model will be as good as the thinned patter is closer to be considered a simulation of a Homogeneous Poisson process.

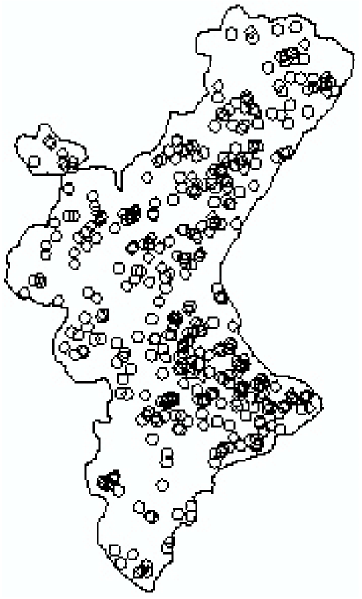
Subset of data

$[T_0, T_1] = [1, 731]$, corresponding to years 2000-2001

Spatial region $[0, 1] \times [0, 2]$ (transformed UTM coordinates)

◇ 412 fires 2000-2001

◇ 258 fires 2001(Summer)



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Results (1)

Model	ν	α	β	ϕ_x	ϕ_y	ϕ_t
1	0.3175319					
2	117			8.944529e-03	3.049596e-03	
2(Summer 01)	19.5			0.005939081	0.073891130	
3		17.4647401				0.3308929
4	3491	10.0011		2.652971e-03	3.625498e-03	3.006663e-01
4(Summer 01)	581.8334	2.912395e-03		5.449081e-03	1.000144e+01	2.930657e-01
5	100	100	3.250635e-03	3.167978e-03	2	

$$
\begin{aligned}
\lambda_1(t,x,y) &= \nu \\
\lambda_2(t,x,y) &= \nu m(x,y) \\
\lambda_3(t,x,y) &= \alpha S(t) \\
\lambda_4(t,x,y) &= \alpha \nu m(x,y) S(t) \\
\lambda_5(t,x,y) &= \nu m(x,y) + \alpha S(t)
\end{aligned}
\tag{1}
$$

Results (2)

Model	β	c_1	c_2	c_3	c_4	c_5
6	0.019917748	0.000402415	0.979023215	1.979102735	2.979160247	3.979202286
7	9.999262e-01	9.984303e-04	9.999934e-01	1.999993e+00	2.999993e+00	3.999993e+00

and for model 7:
$\nu = 100, \phi_x = 0{,}00875, \phi_y = 0{,}0035, \alpha = 1{,}000000e + 02,\ \phi_t = 1.$
where

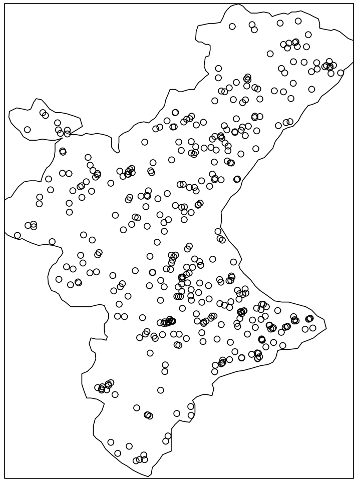
$$\begin{aligned}\hat{I}(t,x,y) = I(t,x,y)[&c_1 W(I(t,x,y) < 0{,}5) + c_2 W(I(t,x,y) \in (1{,}5, 2{,}5)\\ &+ c_3 W(I(t,x,y) \in (2{,}5, 3{,}5)) + c_4 W(I(t,x,y) \in (2{,}5, 3{,}5))\\ &+ c_5 W(I(t,x,y) \in (3{,}5, 4{,}5))]\end{aligned}$$

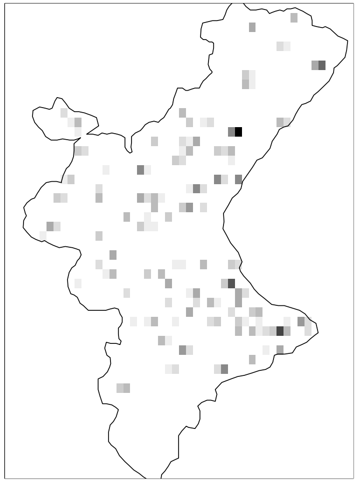
$$\lambda_6(t,x,y) = \beta \hat{I}(t,x,y)$$

$$\lambda_7(t,x,y) = \alpha \nu \beta m(x,y) S(t) \hat{I}(t,x,y)$$

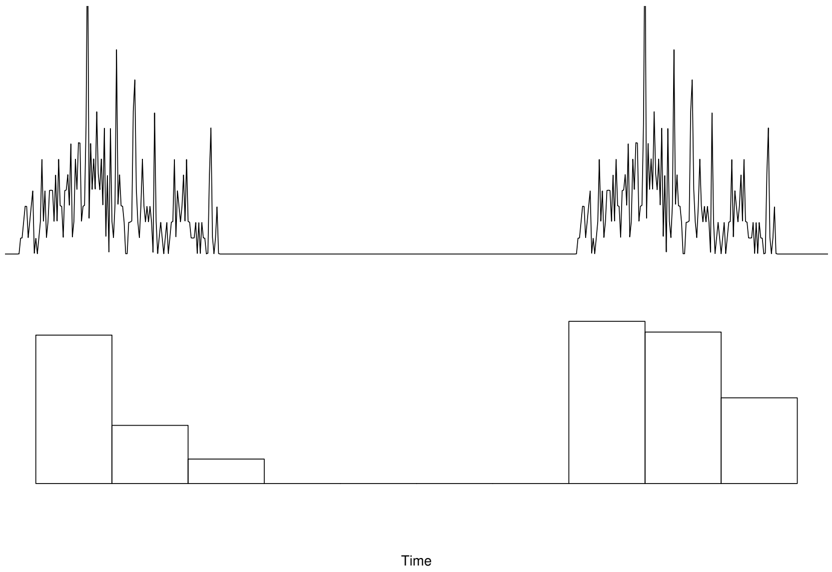
Results (3)

Forest fires in 2000-2001 and fitted intensity function by using model λ_2





Results (4)



Forest fires in 2000-2001 and fitted intensity function by using model λ_3

Goodness of the risk index

Model	AIC
1	1771.272
2	15503.81
2(Summer 01)	**218.8829**
3	1337.061
4	43438.4
4(Summer 01)	15253.74
5	**1095.461**
6	1375.305
7	20544.33

Conclusions

-Minimum AIC: model λ_2 for Summer analysis

-Missing data existence: lots of data had to be filled

-Reduction to Summer with less missing data

-Risk index does not provide much information

-Need to incorporate marks, because LATUV's index is related to the danger associated to each fire