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A double branching model for earthquake forecasting

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Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

CSEP in Japan, Earthquake Research Institute, 27 May 2009, Tokyo

Outline of the presentation

1. The model proposed: rationale and general features

2. Applications of the model: some scientific results

3. Setting and testing the model for Italy

4. Points to take home

❖ It is based on a Stepwise Branching process. The data are analyzed at different steps, in order to get different aspects of the earthquake generation processes (see the Boosting approach). This works well when different physical processes are in play (e.g., co- and post-seismic triggering).

❖ The method deals with regions not single faults; this implies limits in the spatial resolution, but we do not mind about possible incompleteness of the faults catalog.

❖ We have used the model to explore different spatial-time-magnitude window (different seismic catalogs) in order to check how the model parameters vary.

❖ The model has been submitted to different CSEP testing regions (Global, 1yr; Western Pacific, 1 yr.; Italy, 3 months; Japan, 1 yr.?)

Double Branching Model

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Double Branching Model (1°step)

SHORT TERM INTERACTIONS

$$\lambda_1(t,x,y) = \mathbf{v}_1 \cdot u_1(x,y) + \sum_{t_i<t}\left[\frac{\mathbf{k}_1}{(t-t_i+\mathbf{c})^{\mathbf{p}}} e^{\alpha_1(M_i-M_0)} \frac{c_{d_1 q_1}}{(r^2+\mathbf{d}_1{}^2)^{q_1}}\right]$$

***E**pidemic **T**ype **A**ftershocks **M**odel*

(Ogata, 1988,1998)

Double Branching Model (Declustering)

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Declustering procedure

Zhuang et al., 2002

$$\pi_i = \frac{v_1 \cdot u_1(x_i, y_i)}{\lambda(t_i, x_i, y_i)}$$

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Double Branching Model (2°step)

SHORT TERM INTERACTIONS

$$\lambda_1(t,x,y) = \boldsymbol{\nu}_1 \cdot u_1(x,y) + \sum_{t_i<t}\left[\frac{\mathbf{k}_1}{(t-t_i+\mathbf{c})^{\mathbf{p}}} e^{\alpha_1(M_i-M_0)} \frac{c_{d_1 q_1}}{(r^2+\mathbf{d}_1{}^2)^{q_1}}\right]$$

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LONG TERM INTERACTIONS

$$\lambda_2(t,x,y) = \boldsymbol{\nu}_2 \cdot u_2(x,y) + \sum_{t_i<t}\left[\mathbf{k}_2 e^{-\left(\frac{t-t_i}{\tau}\right)} e^{\alpha_2(M_i-M_0)} \frac{c_{d_2 q_2}}{(r^2+\mathbf{d}_2{}^2)^{q_2}}\right]$$

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Double Branching Model (2°step)

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Poisson Model

Declustering procedure

Zhuang et al., 2002

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Branching Model

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τ relaxation time

$e^{-t/\tau}$ model proposed by

[Piersanti 1991; Piersanti et al.,1995; 1997]

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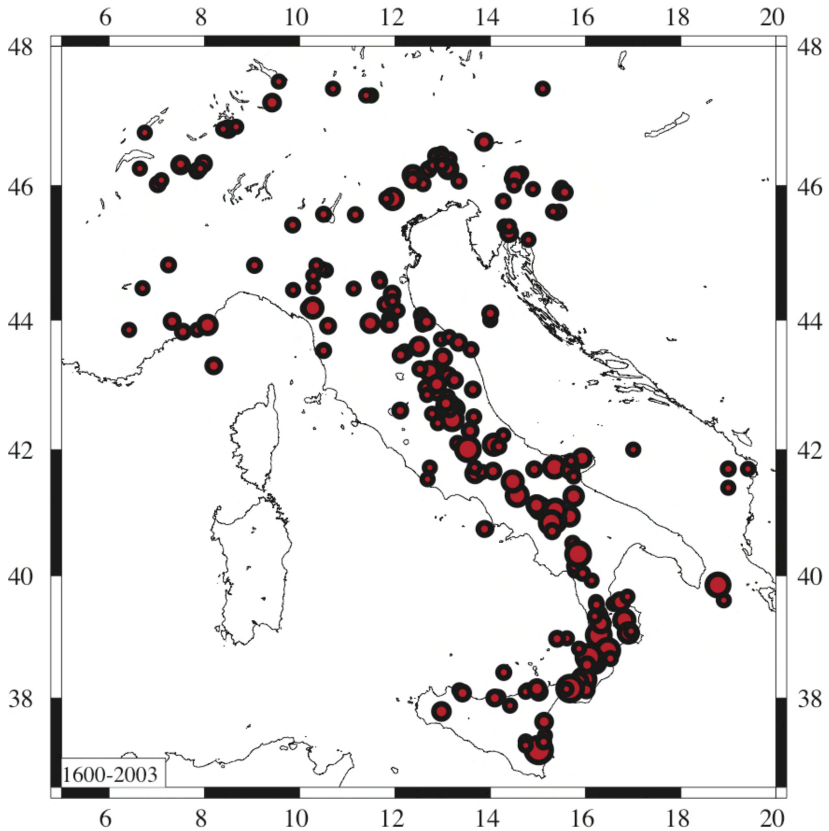
Double Branching Model: evidence of long-term clustering



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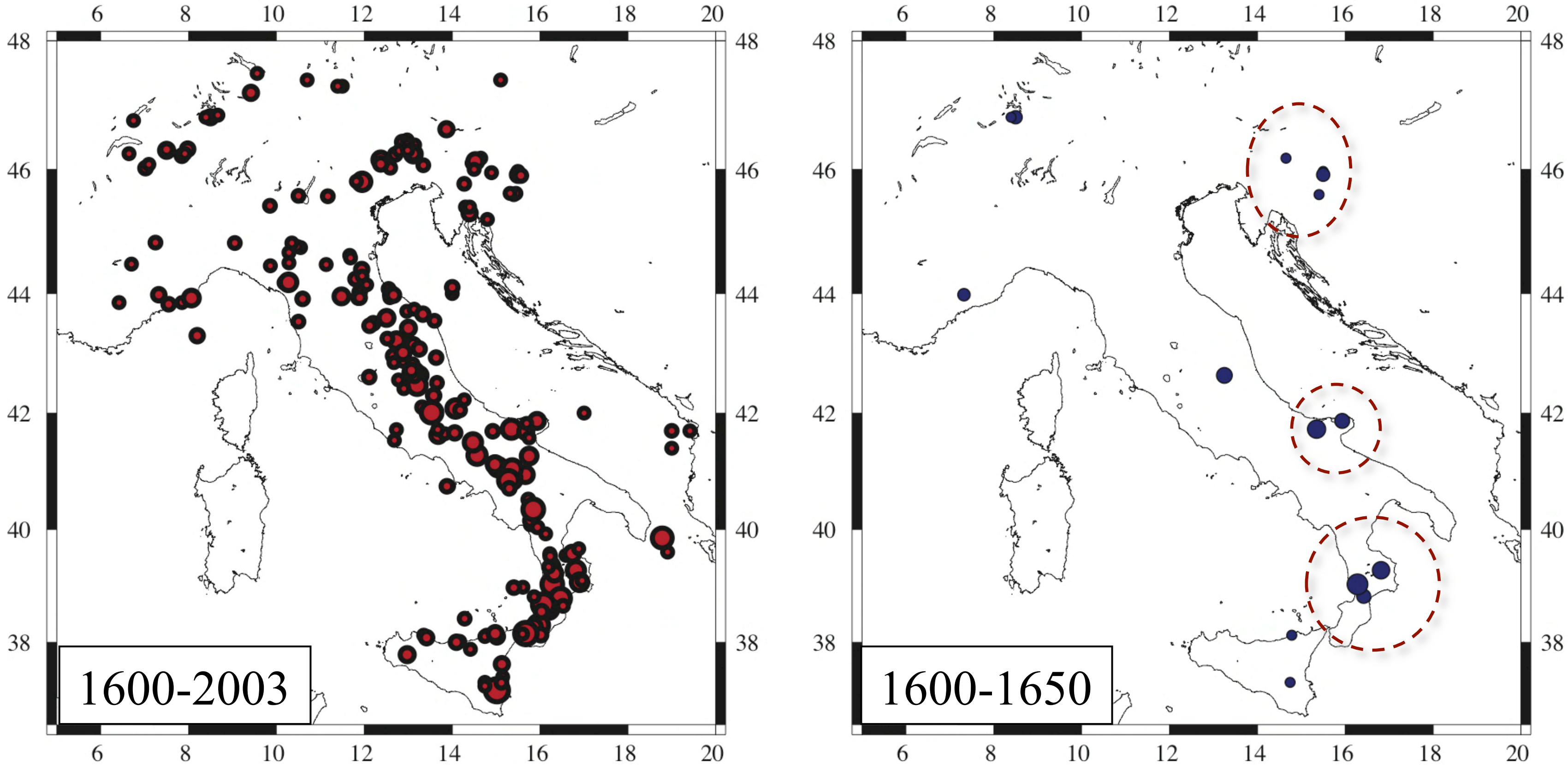
Double Branching Model: evidence of long-term clustering



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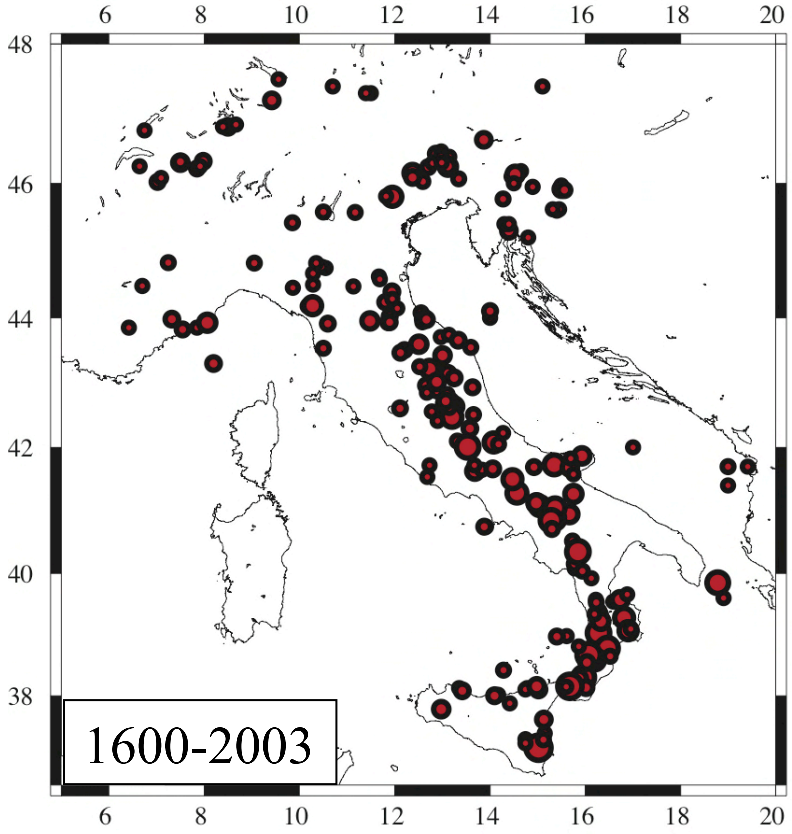

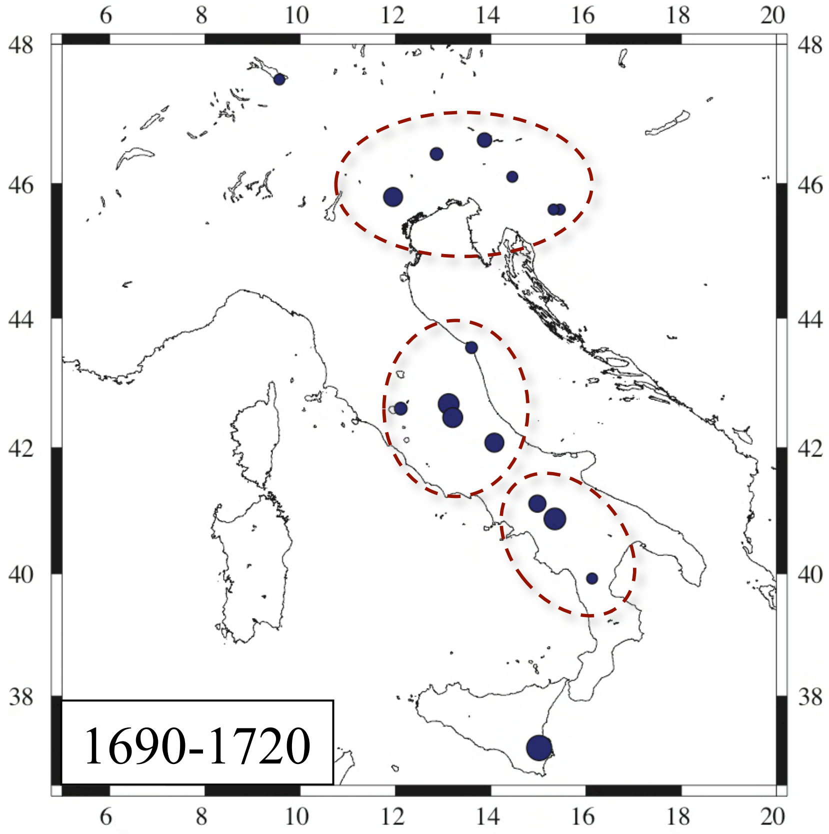

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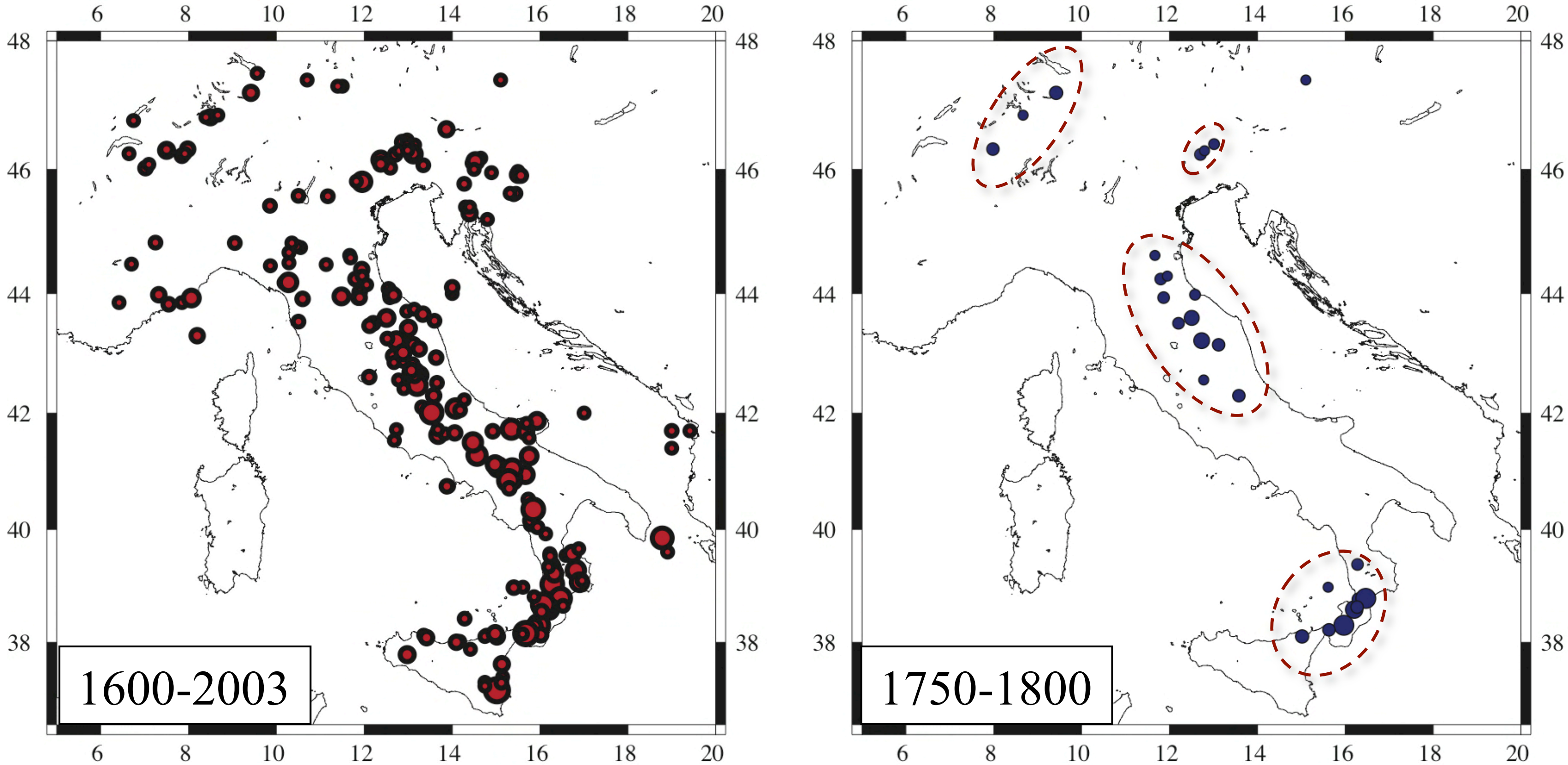

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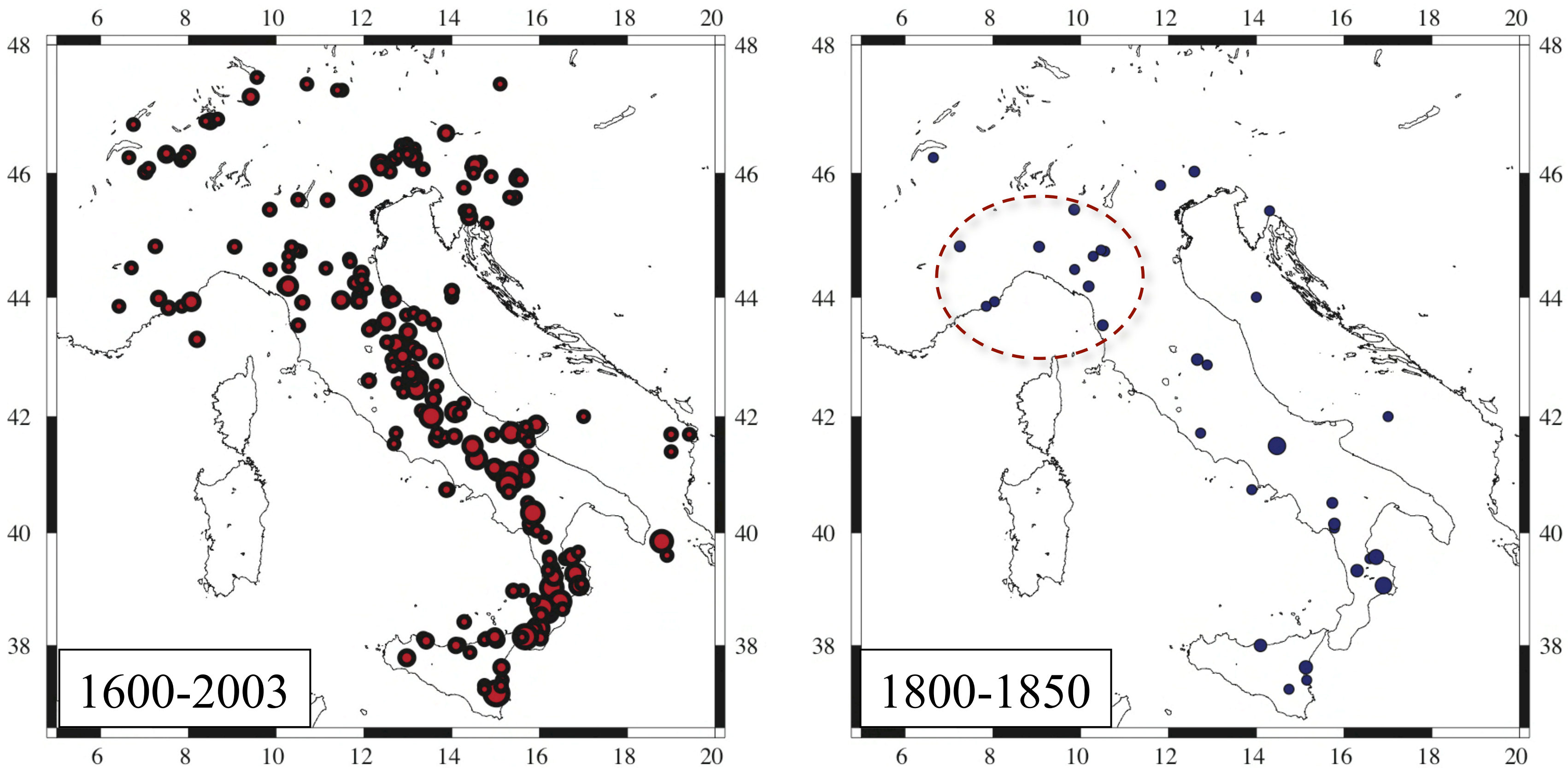

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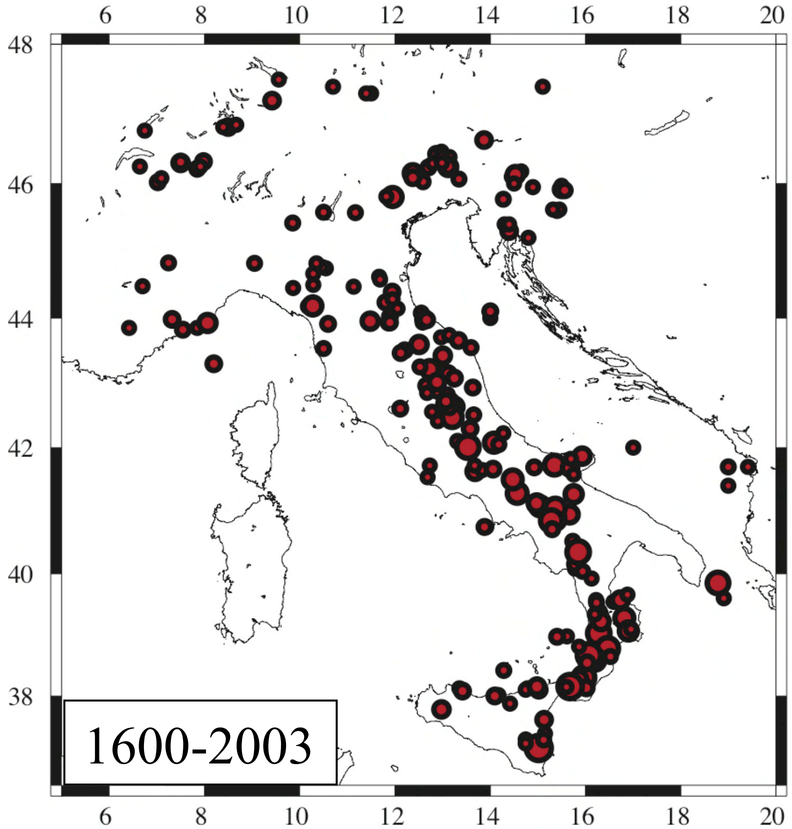

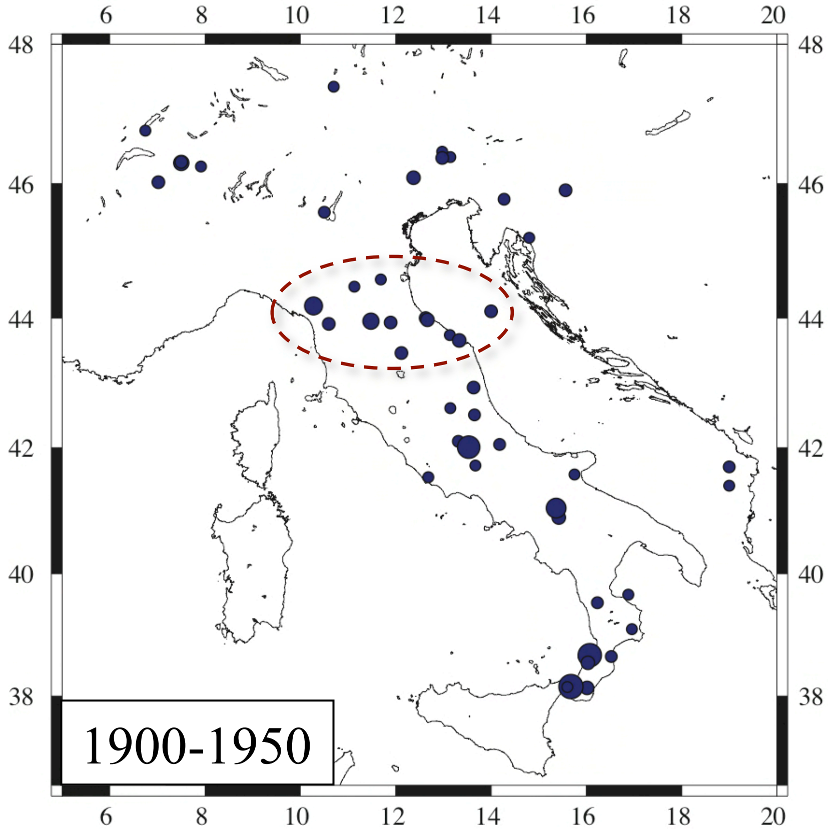

- The model has been applied to the Pacheco and Sykes (1992) catalog: Ms 7.0+, max depth 70 km, 698 earthquakes in the time interval 1900-1989. NEIC catalog; Ms 6.0+, max depth 70 km, 3590 earthquakes in the time interval 1974-2006. Italian CPTI04 catalog: Mw 5.5+; 203 earthquakes in the time interval 1600-2003.
- The model always perform better than a stationary ETAS model and Poisson
- There is always a significant time variation of the "background" (K_2 is always significantly different from zero)
- The time variation has always a characteristic time τ of about 30 years (post-seismic relaxation?)
- The other parameters of the model are similar to values obtained for aftershock sequences (universality?)

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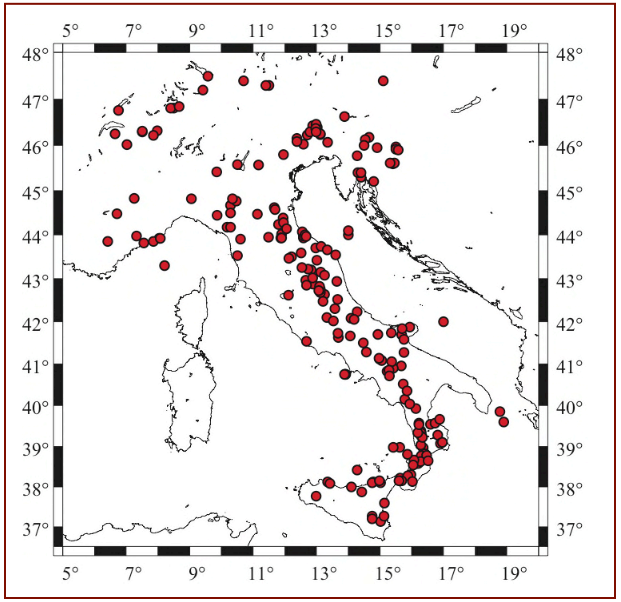
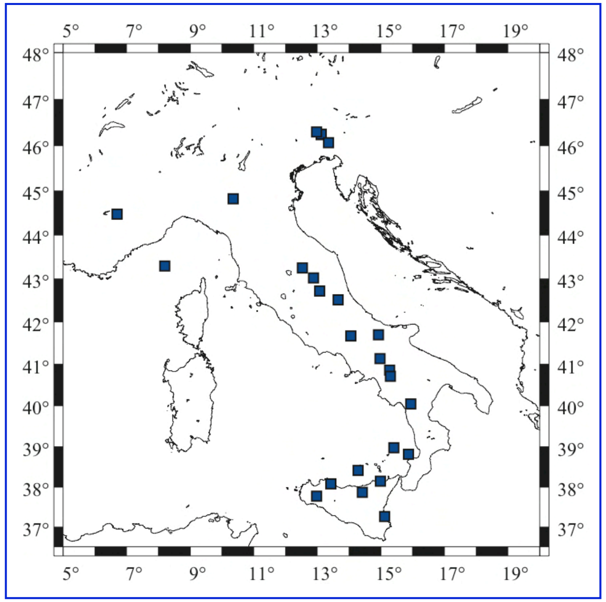
Historical seismicity in Italy: CPTI catalog

***C**atalogo* ***P**arametrico* ***T**erremoti* ***I**taliani* **catalog**

1600-2003, Mw ≥ 5.5, 203 events



CPTI *Learning* database
1600-1950
176 events



CPTI *testing* database
1950-2003
27 events

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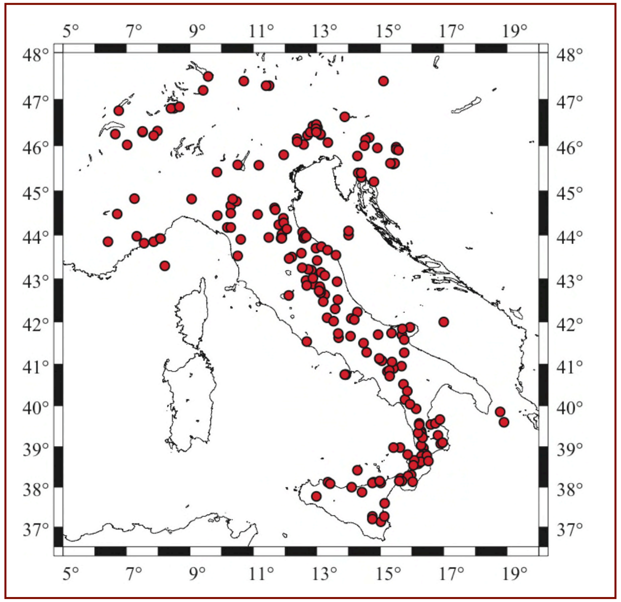

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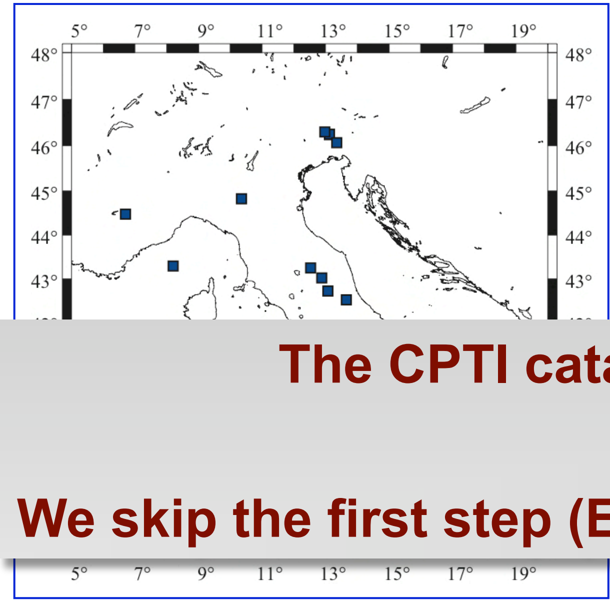

The CPTI catalog is just declustered

We skip the first step (ETAS modeling) of our procedure!

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CPTI catalog: Modeling

long-term clustering

$$\lambda_2(t,x,y) = \mathbf{v}_2 \cdot u_2(x,y) + \sum_{t_i<t} \left[\mathbf{k}_2 e^{-\left(\frac{t-t_i}{\tau}\right)} e^{\alpha_2 (M_i - M_0)} \frac{c_{d_2 q_2}}{(r^2 + \mathbf{d}_2{}^2)^{q_2}} \right]$$

tectonic loading

Parameter	Poisson Model	Second Branching Model
ν_2	0.50 ± 0.04 year^{-1}	0.23 ± 0.04 year^{-1}
K_2		0.019 ± 0.004
τ		34 ± 6 year
α_2		~ 0.0
d_2		21 ± 7 km
q_2		1.7 ± 0.2
Log-lik	-2725.6	-2660.5

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Branching Model better than Poisson Model?

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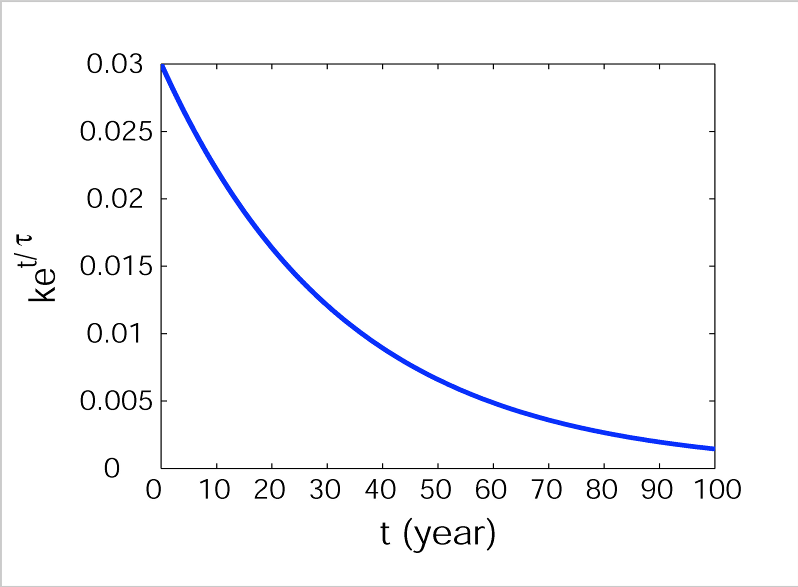

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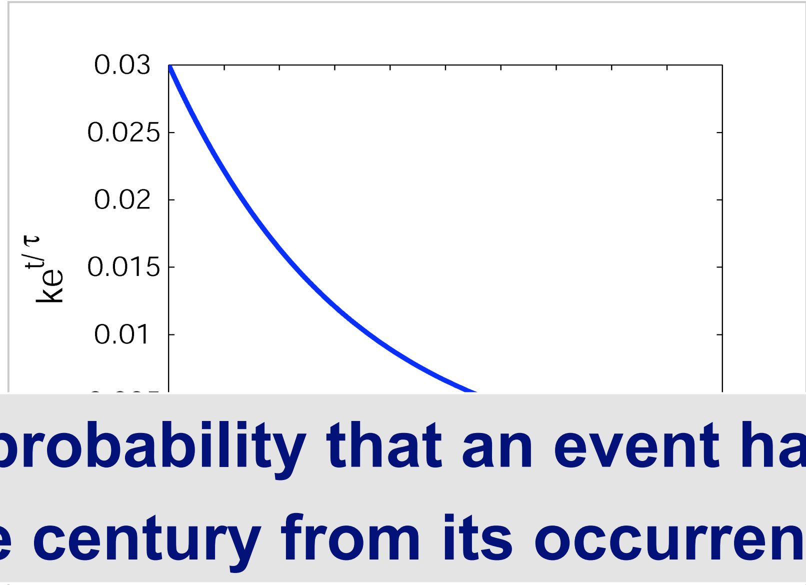

We have a not negligible probability that an event has a triggering effect after one century from its occurrence

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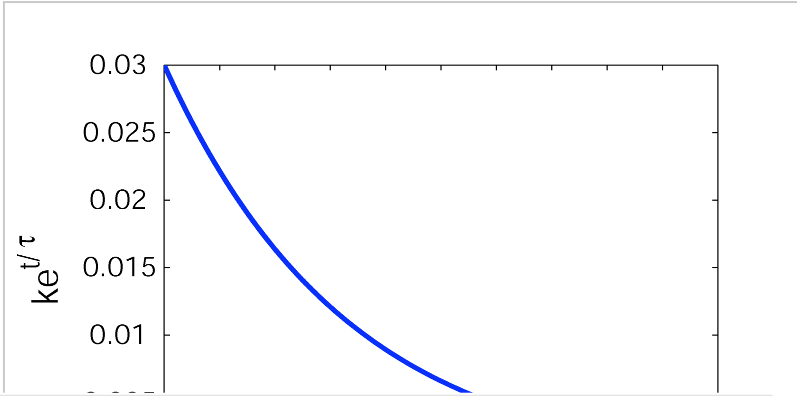

Long-term Clustering: universal law?

Pacheco and Sykes catalog (1900-1990, Mw ≥ 7.0) τ = 36 ± 7 year

NEIC catalog (1974-2006, Mw ≥ 6.0) τ = 30 ± 5 year

(Marzocchi and Lombardi, 2008)

CPTI catalog: Testing

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$\mathcal{H}_0$: **Poisson Process**

$\mathcal{H}_1$: **Branching model**

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Information gain

$$IGpe = \frac{LogL_1 - LogL_0}{N}$$

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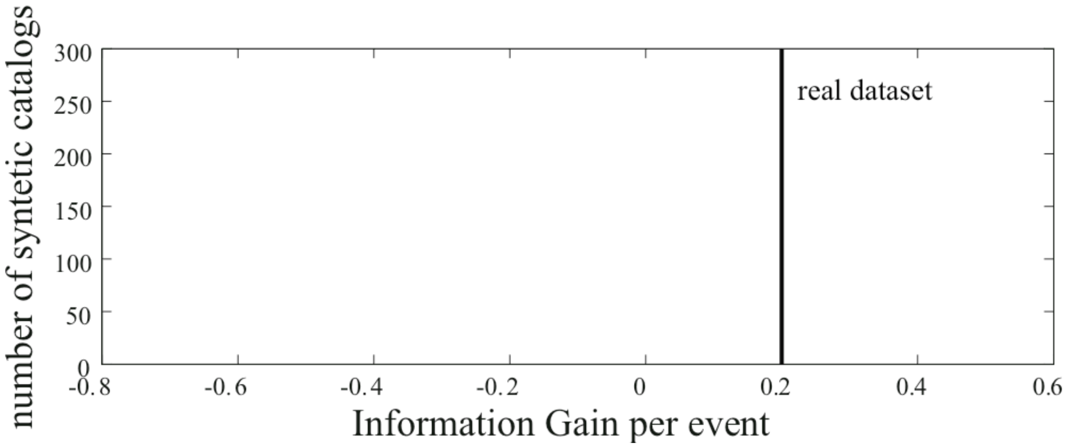

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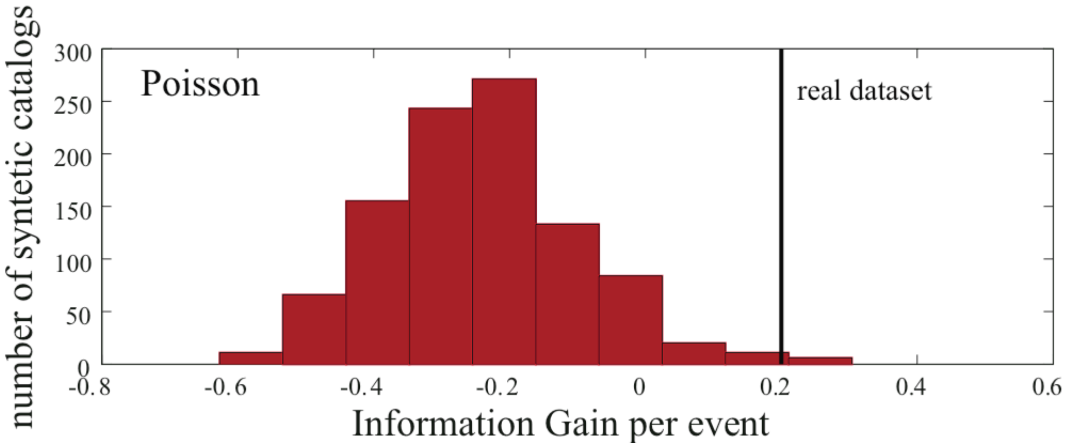

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CPTI catalog: Testing

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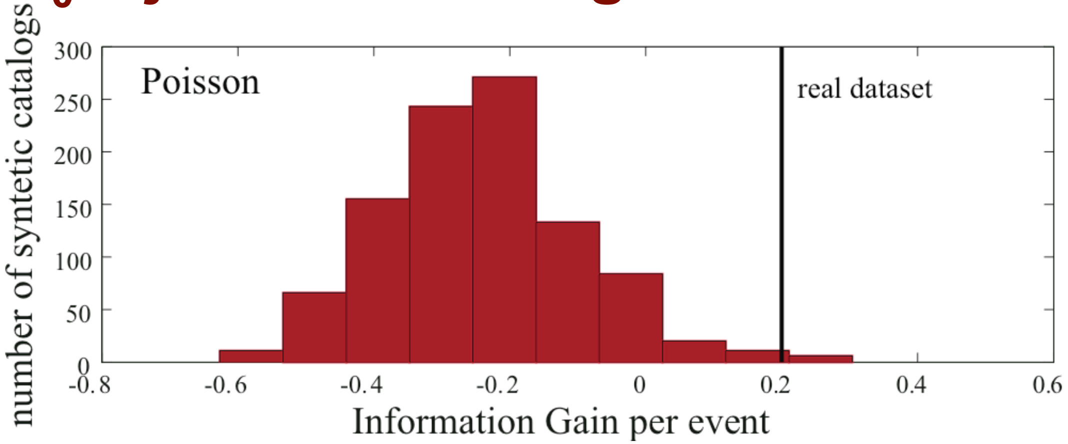
$\mathcal{H}_0$ rejected at 1% significance level!



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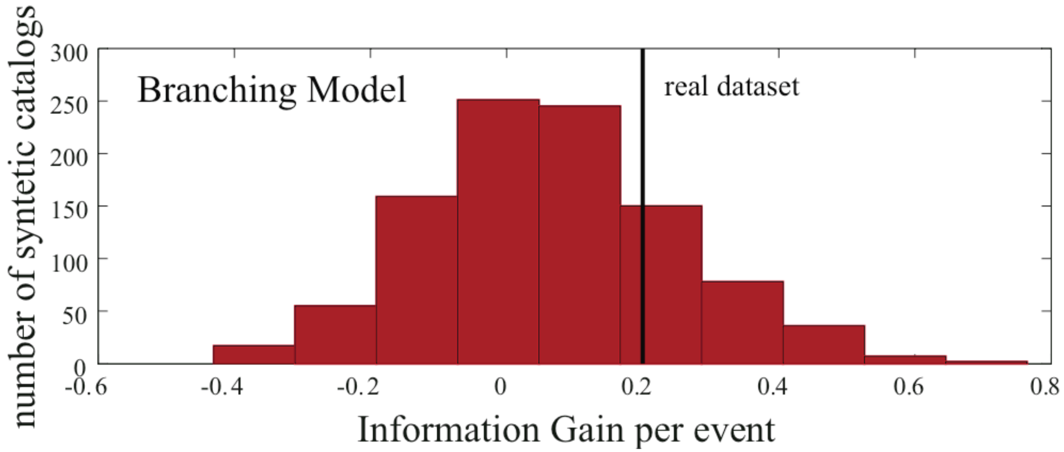

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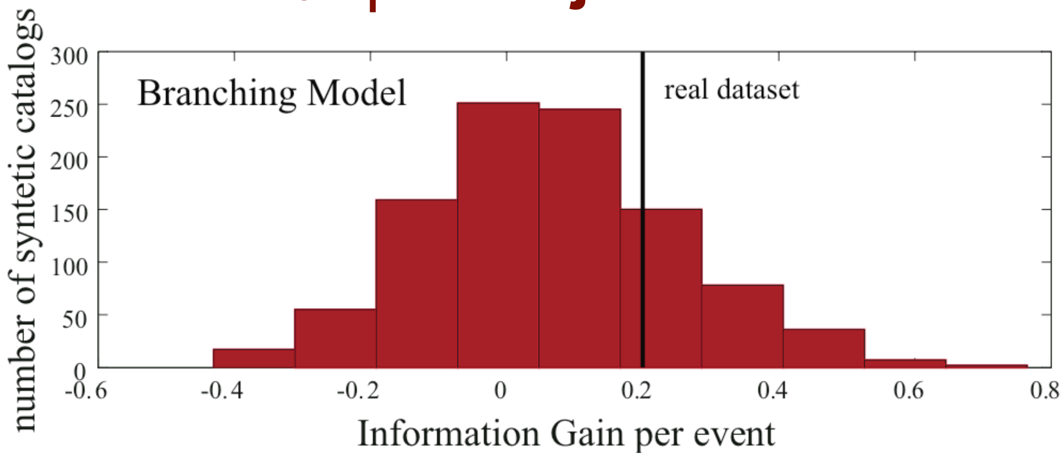
$\mathcal{H}_1$ not rejected!



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CPTI catalog: Forecasting

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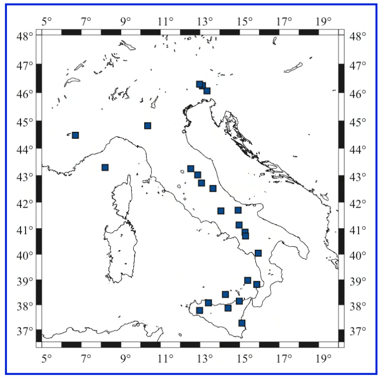
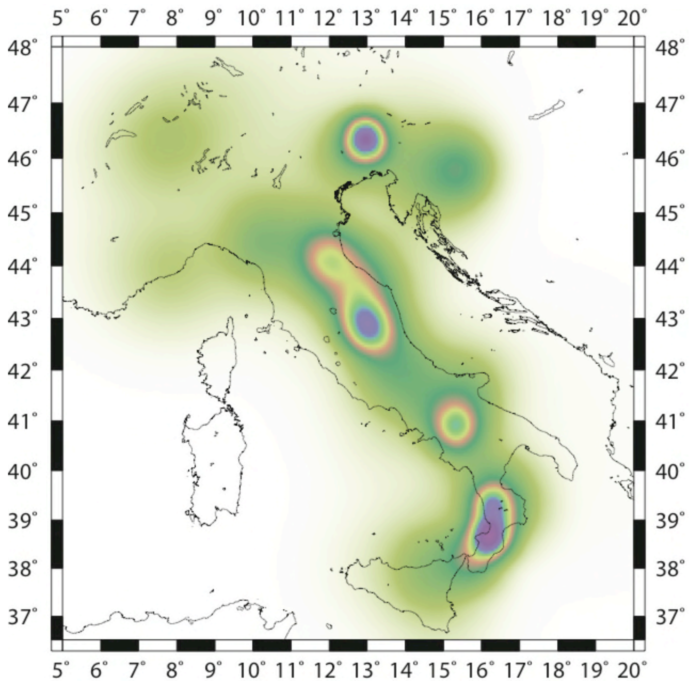
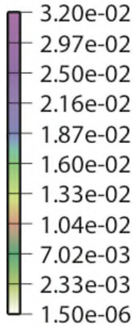


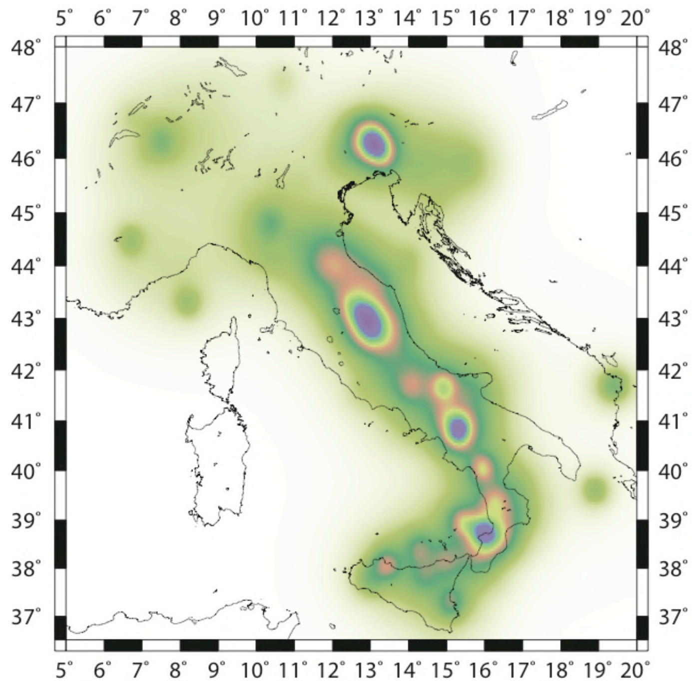
50 years: 2008-2057

Poisson Model





Branching Model



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Points to bring home

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- the most reliable physical explanation could be the postseismic stress transfer

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- the historical seismicity occurred in Italy shows a long-term clustered behaviour
- universality (indipendence by magnitude-space-time range)
- one of the most reliable physical explanations could be the postseismic stress transfer
- implication for seismic hazard assessment

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Points to bring home

- the historical seismicity occurred in Italy shows a long-term clustered behaviour
- universality (indipendence by magnitude-space-time range)
- one of the most reliable physical explanations could be the postseismic stress transfer
- implication for seismic hazard assessment
- the model is set and running for global test, Western Pacific, and Italy (soon). Aim: to submit it for Japan (1 yr forecast).