FAULT based PSHA

Pisa, 27-30 September 2021

Turn Fault Data into Seismic-Hazard Models: Assumption & consequences

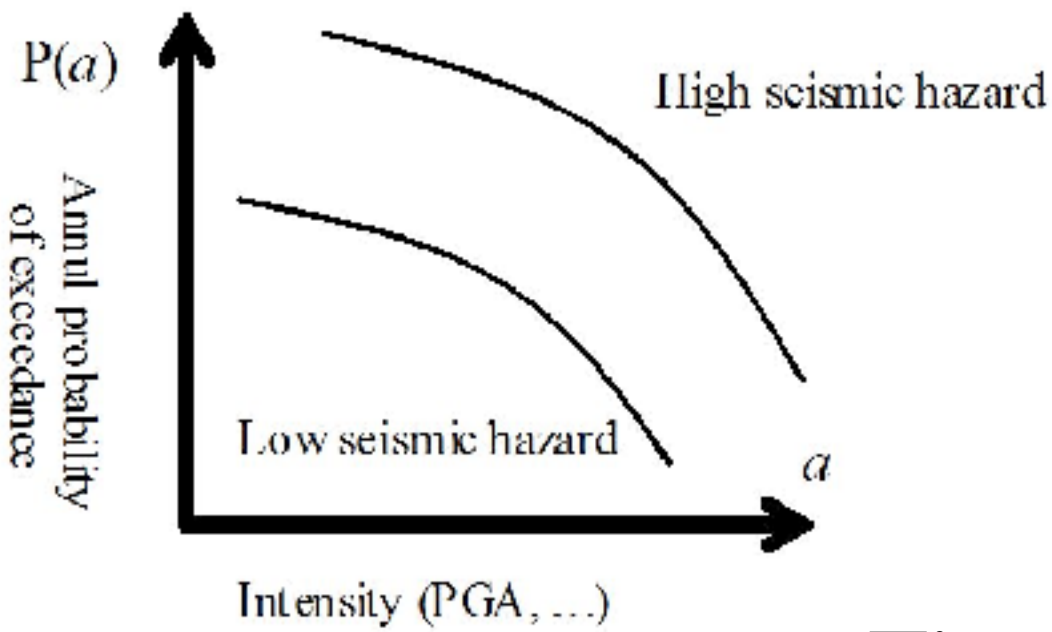
Bruno Pace
Università "G- d'Annunzio" Chieti-Pescara
Italy

Università degli Studi "G. d'Annunzio"

fault2sha

Do we need to model active faults in SHA?

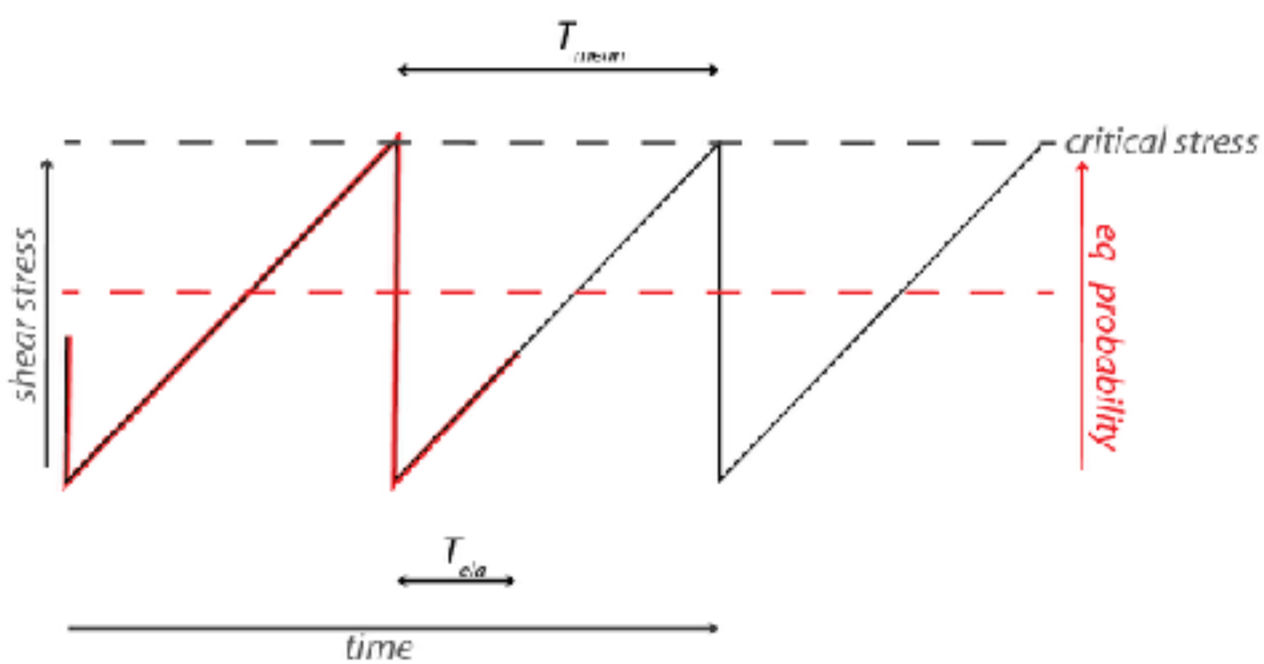
PSHA quantifies the probability of exceeding specified levels of ground motion at a site, given the range of possible earthquakes during a specific period of time.

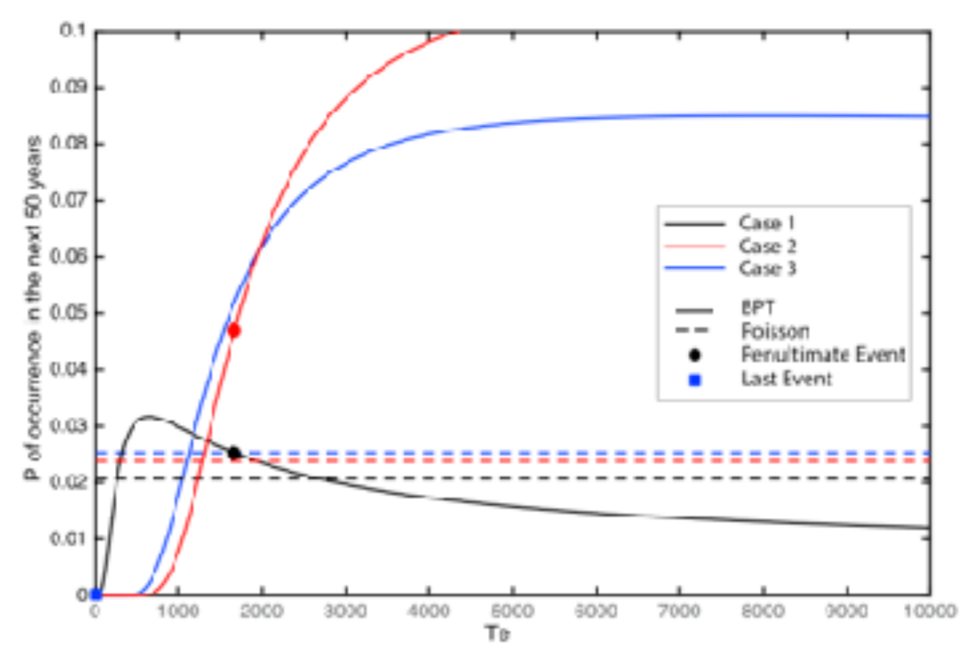


$$P(A) = 1 - e^{-\lambda \Delta t} \approx \lambda \Delta t$$

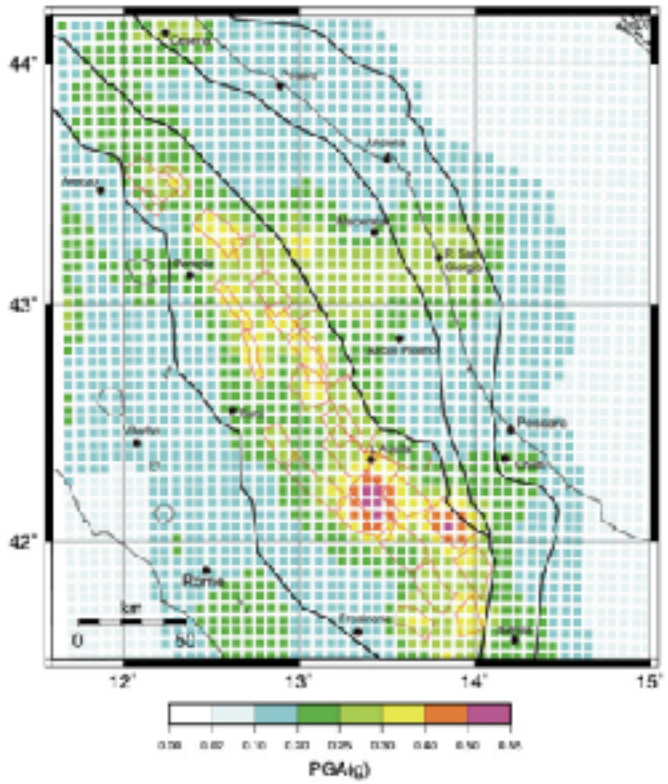
$$\boxed{\lambda = \frac{N}{\Delta T}}$$

Time dependency



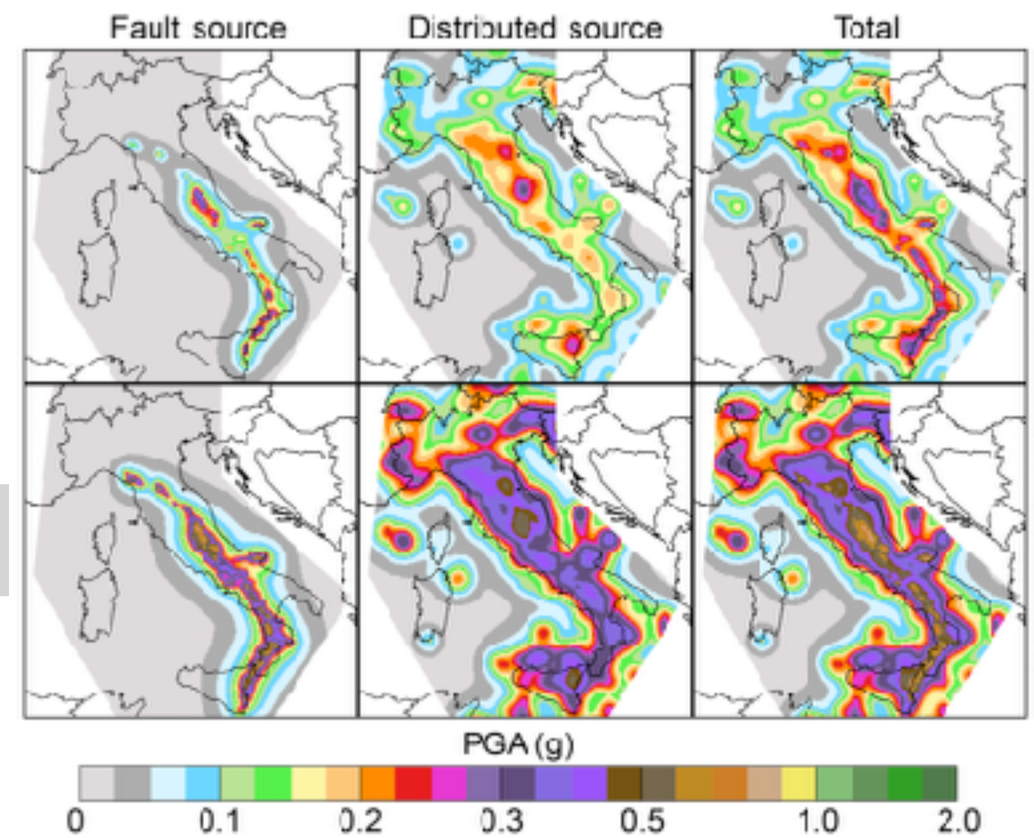


Do we need to model active faults in SHA?



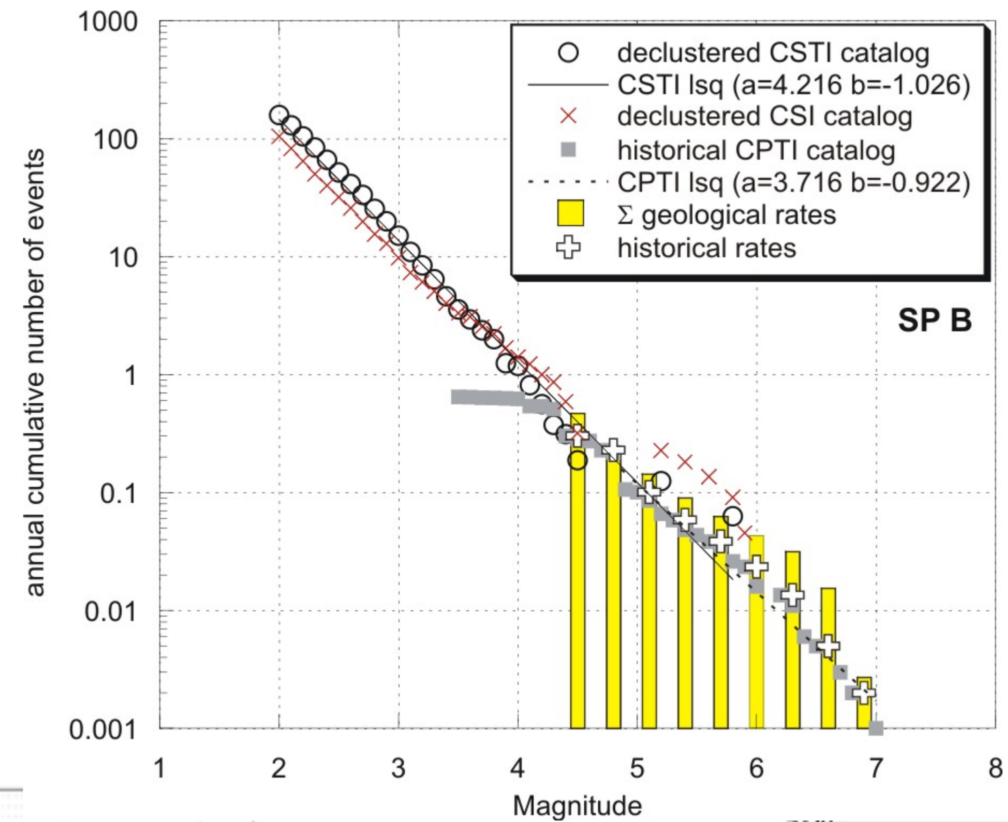
Pace et al. 2006 BSSA

Peruzza et al. 2011 BSSA

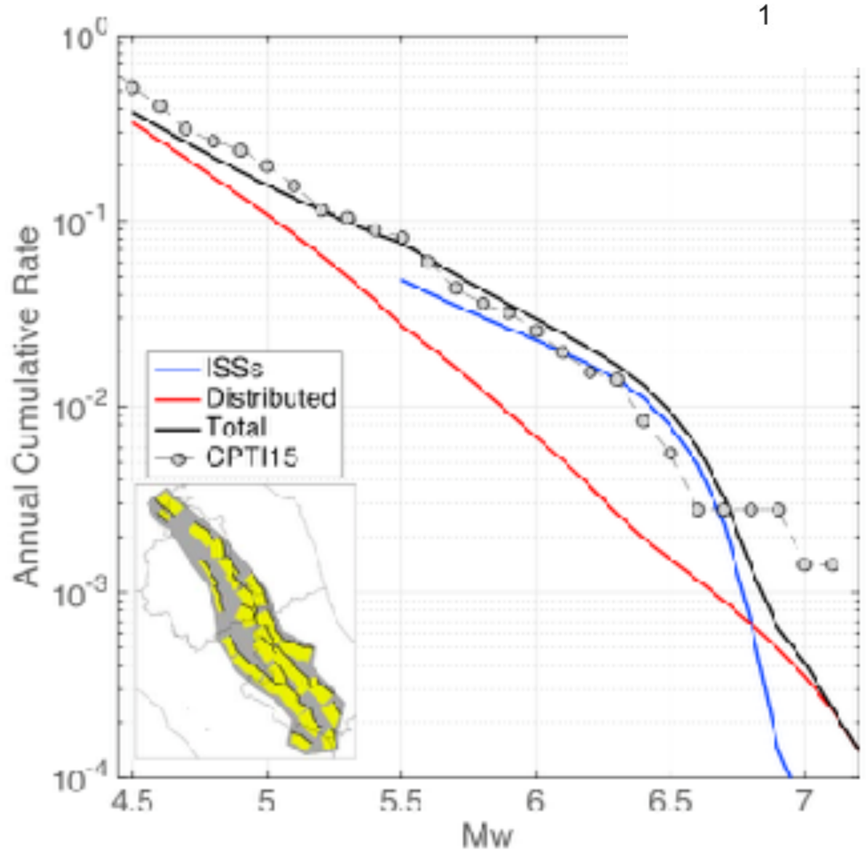


Valentini et al. 2017 NHESS

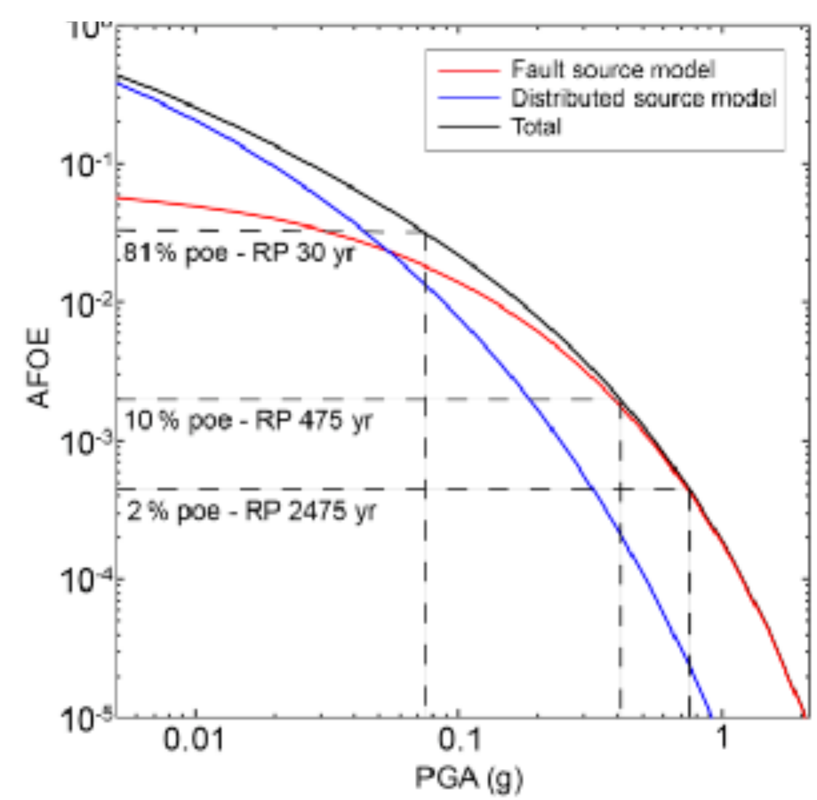
Do we need to model active faults in SHA?



Pace et al. 2006 BSSA



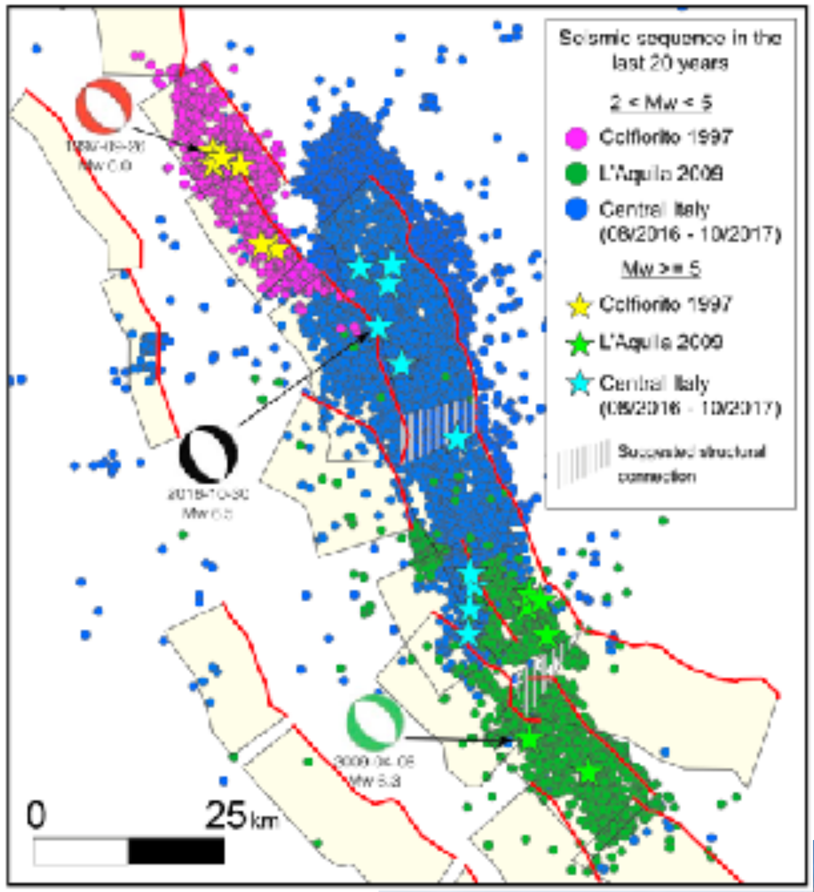
Valentini et al. 2019 Tectonics



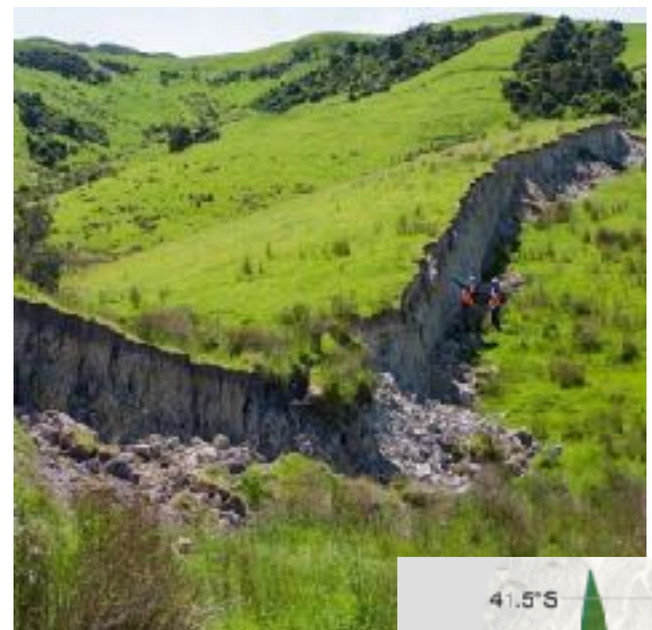
Valentini et al. 2017 NHESS

new data conforming complexities

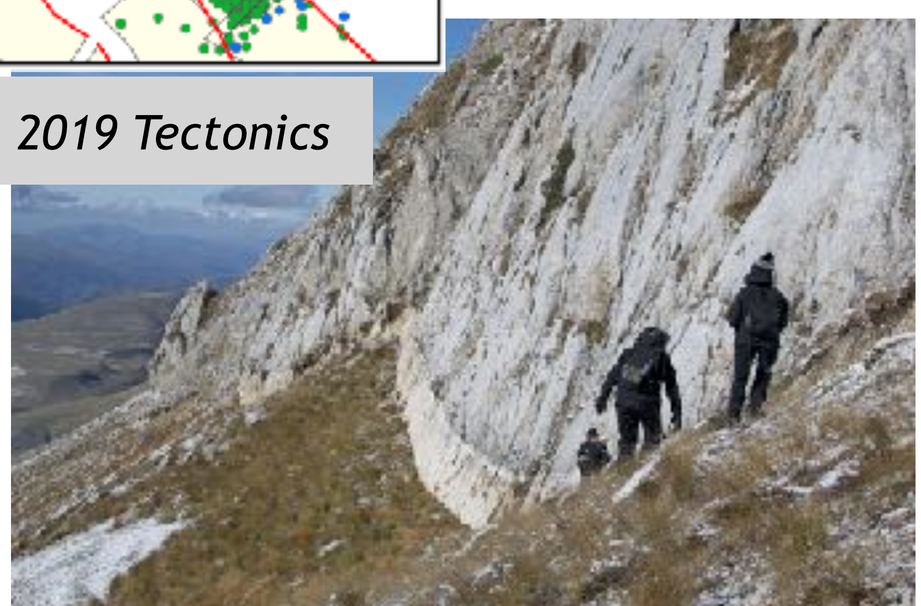
segmented vs. unsegmented rupture models



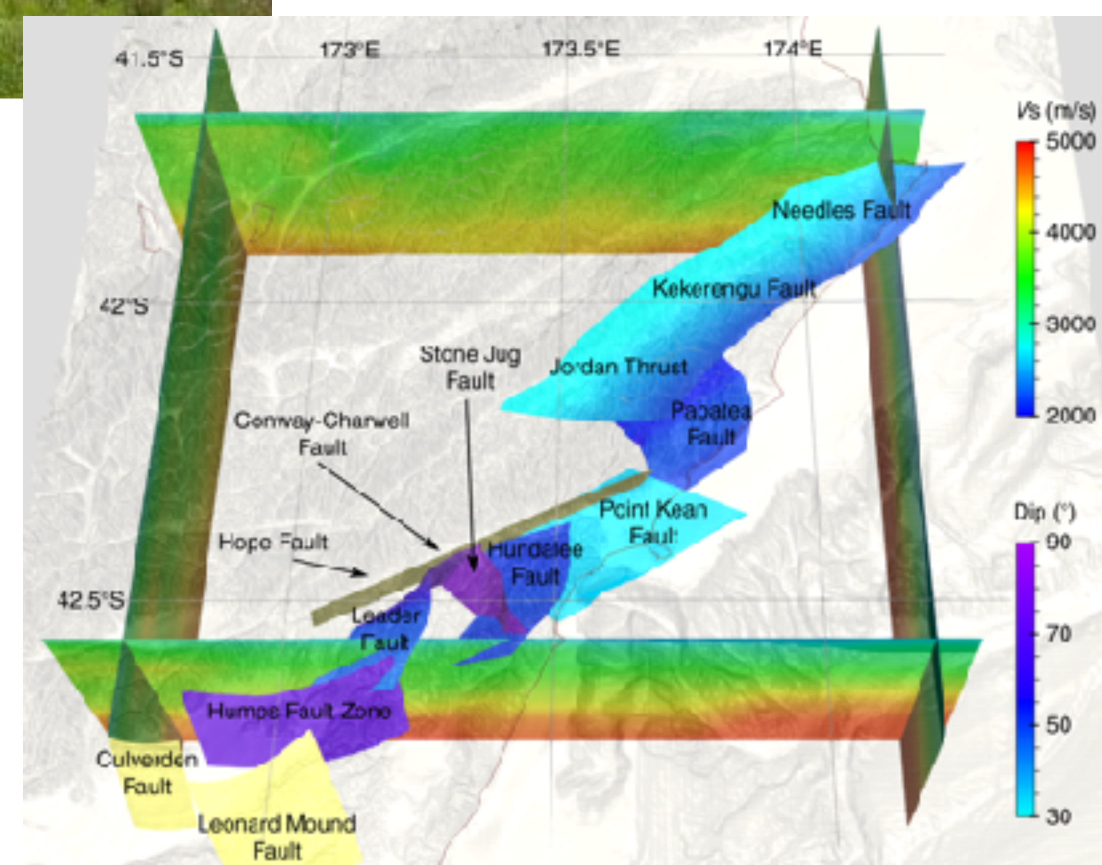
Valentini et al. 2019 Tectonics



?

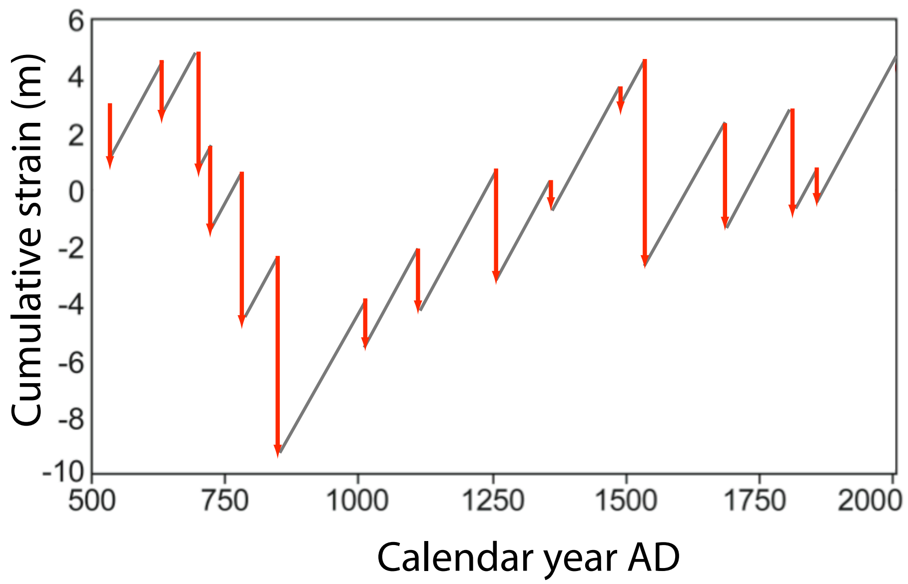


Ulrich et al. 2019 Nature comm.



new data conforming complexities

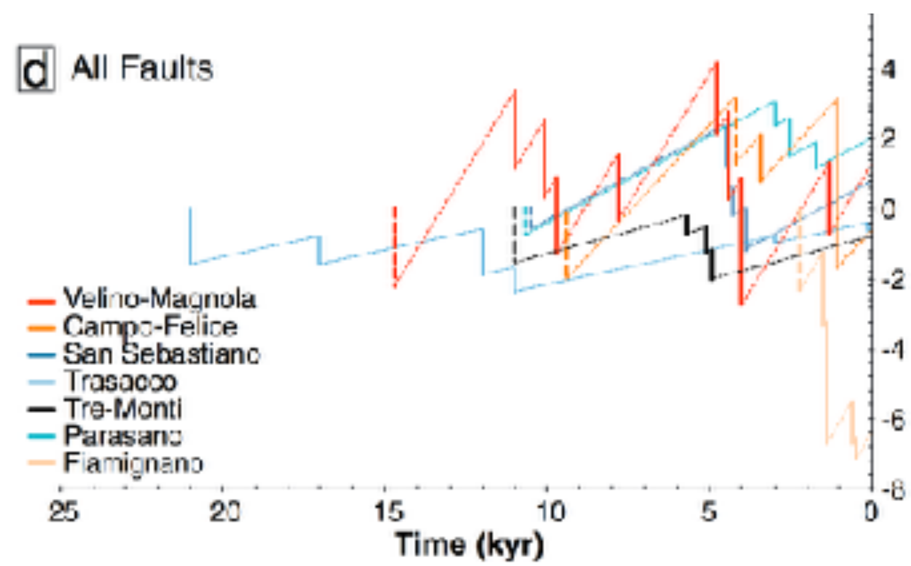
Clustering



San Andreas Fault, Weldon et al., 2004

trenching

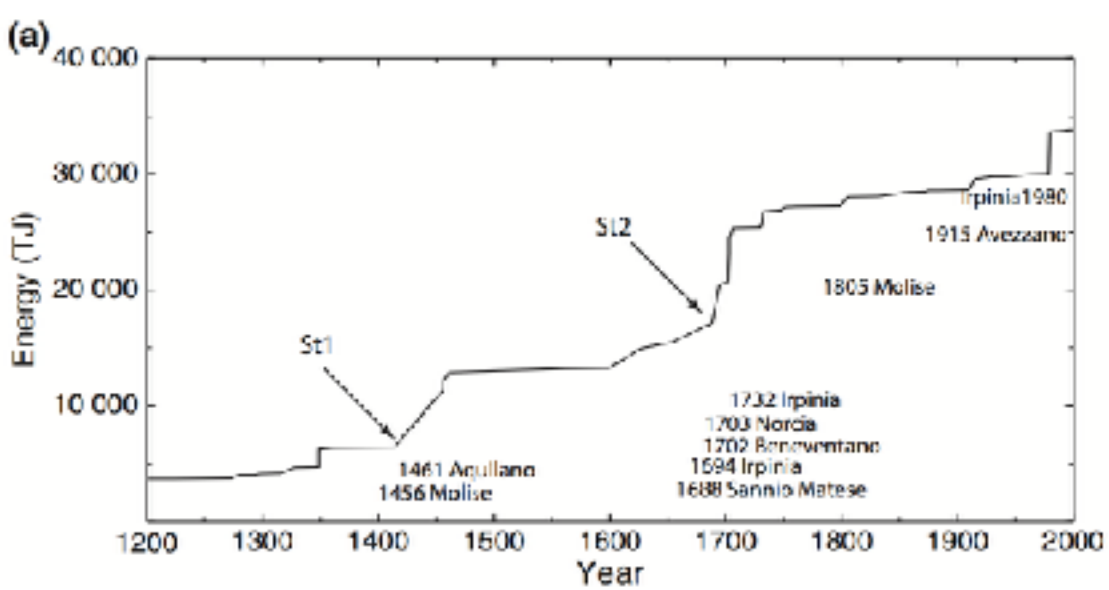
Synchronicity



Central Italy, Benedetti et al., 2013

36Cl exposure dating

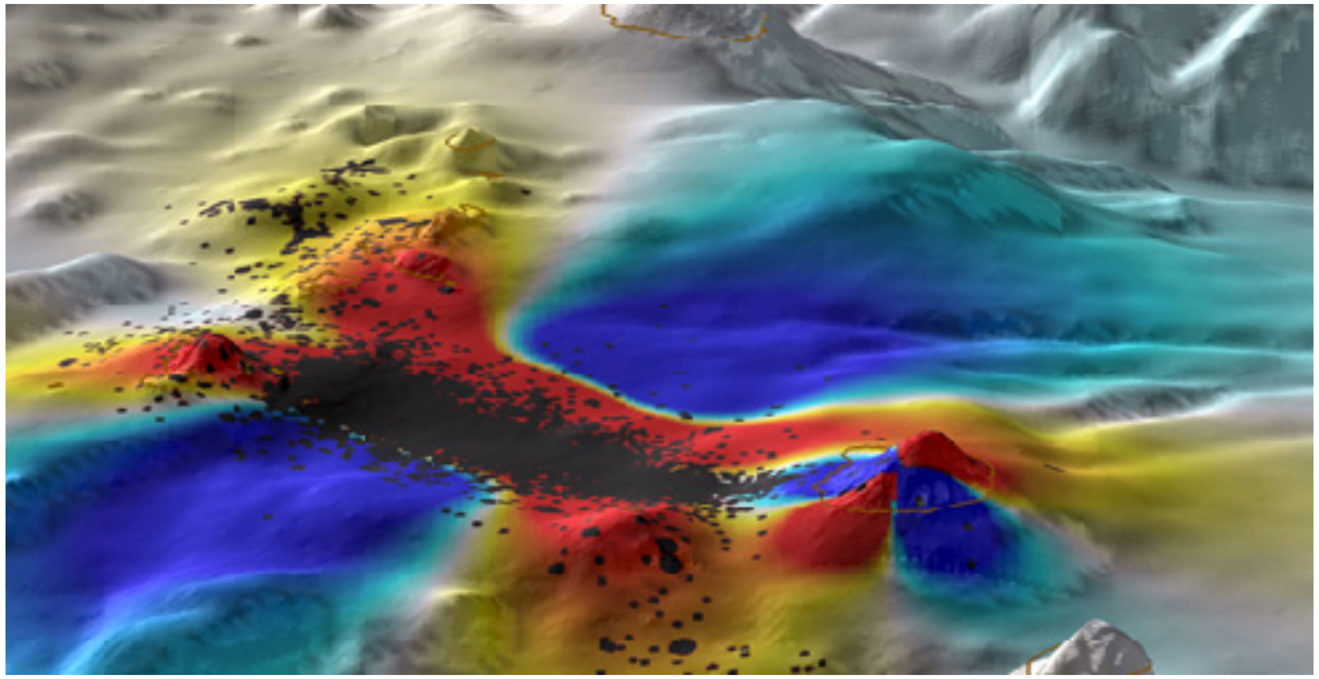
Eq storms



seismology

Central Italy, Chiarabba et al., 2011

Fault interaction



- fault interaction and seismic hazard models
- relaxing the segmentation model in SHA

space

time

Do we need to model active faults in SHA?

Yes, if we want to complete the information available in the earthquake catalogues and if we want to overcome the Poisson hypothesis.

We have to work on relaxing the segmentation and to include fault interaction in the SH models

How we can use fault data in SHA?

FiSH: MATLAB Tools to Turn Fault Data into Seismic-Hazard Models

FiSH 1.02

ELECTRONIC SEISMOLOGIST

FiSH: MATLAB Tools to Turn Fault Data into Seismic-Hazard Models

by B. Pace, F. Visini, and L. Peruzza

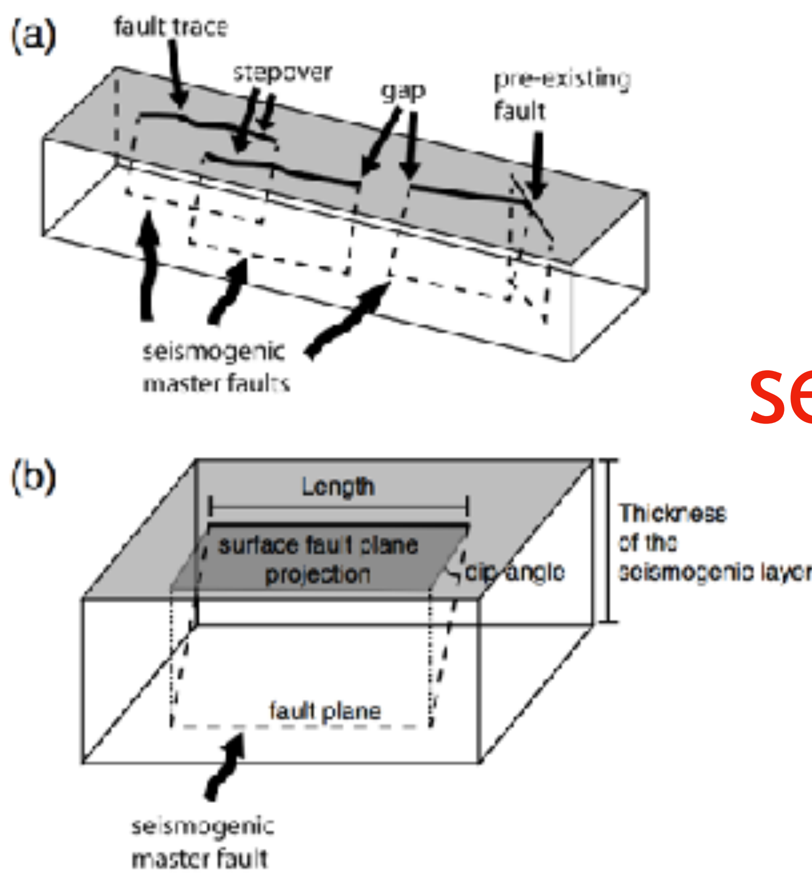
Università degli Studi "G. d'Annunzio"

OGS

INGV

Introduction

<u>The basic assumption</u> of *FiSH* is that the geometric and kinematic features of a fault are the expression of its seismogenic potential



segmented rupture models

<u>Three tools:</u>

-**Moment Budget (MB):** it converts fault geometry and slip rates into global budget of the seismic moment released in a given time frame

-**Recurrence Parameter (RP):** it computes the recurrence parameters and associated uncertainties from historical and/or paleoseismological data

Activity Rates (AR): it outputs time-independent or time-dependent earthquakes rates from different MFD models

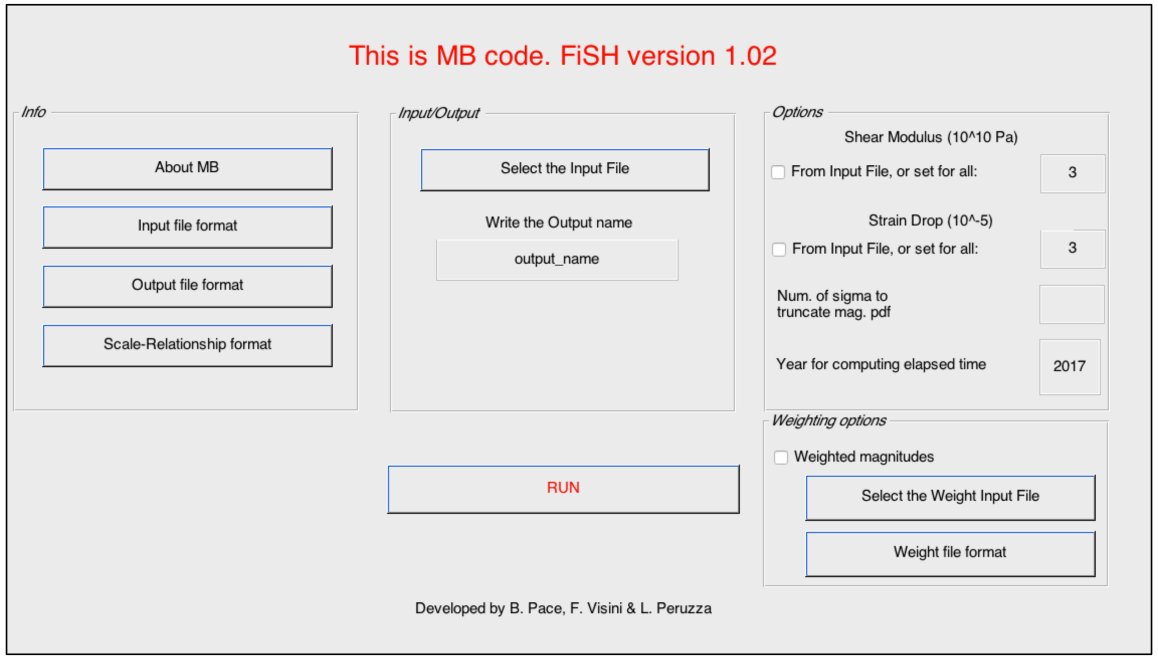
Introduction

FiSH is written in **MATLAB**, a Mathworks commercial software package widely used by geosciences researchers.

A MATLAB license is **<u>mandatory</u>** to run *FiSH*.

But, due to FiSH's graphical user interface, **<u>no knowledge</u>** of the MATLAB language **<u>is required</u>** to use the tools.

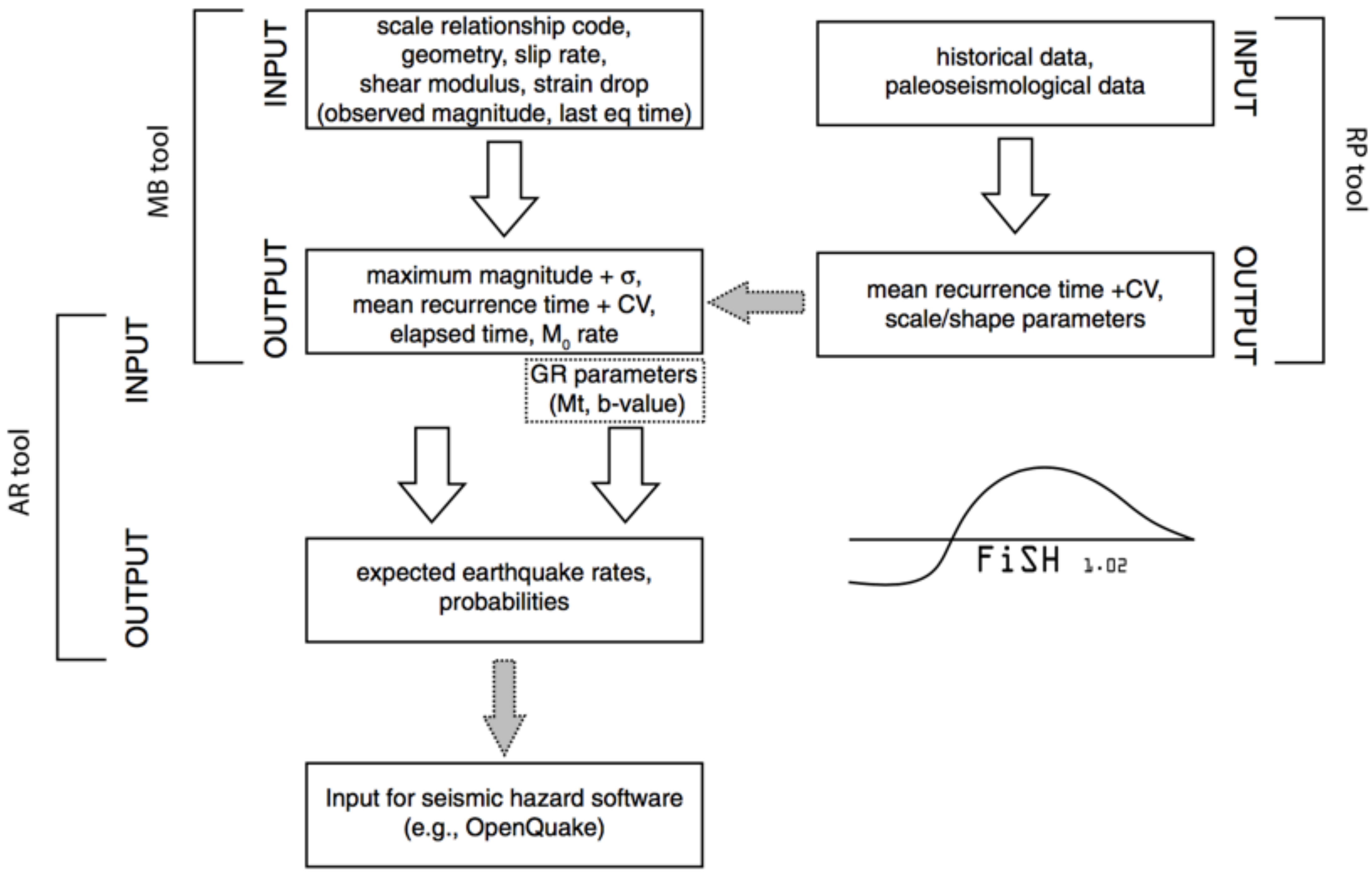
MATLAB



The source codes are available at: http://fault2sha.net/what/tools/

Introduction

The basic assumption of *FiSH* is that the geometric and kinematic features of a fault are the expression of its seismogenic potential



MB tool

MB **combines** standard data that were collected for faults or are assumed to be known, such as the **size** and **rheological properties**, with **empirical size-magnitude relationships** and allows for the treatment of their uncertainties.

Input list:

1)Fault name
2)Scale relationship code
3)Length along strike (km)
4)Dip angle (degrees)
5)Seismogenic Thickness (km)
6)Min and Max slip rate (mm/yr)
7)Maximum observed magnitude (Mw, if any)
8)Standard deviation of Mobs
9)The date of the last event (year, if any)
10)Shear modulus
11) Strain drop

MANDATORY

OPTIONAL

MB tool

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MANDATORY

10)Shear modulus
11) Strain drop

OPTIONAL

MB tool

Scale relationships implemented in MB Tool and their code

Wells and Coppersmith (1984) relationships:
WC94-N - normal faults
WC94-R - reverse faults
WC94-S - strike slip faults
WC94-A - all the kinematics

Leonard (2010) relationships:
Le10-D - dip slip faults
Le10-S - strike slip faults
Le10-SCR - stable continental regions

Volcanic context relationships (Azzaro et al., 2015; Villamor et al., 2001):
Volc - all the kinematics

MB tool

Input file for MB Tool…. A simple .txt file

input_MB_madrid.TXT

```
name ScR Length Dip Seismogenic_Thickness SRmin SRmax Mobs sdMobs Last_eq_time
AlhamaDeMurciaS1 WC94-A 30 70 12 0.5 1.0 NaN NaN NaN
AlhamaDeMurciaS2 WC94-A 20 70 12 0.3 1.0 NaN NaN NaN
AlhamaDeMurciaS3 WC94-A 12 70 12 0.07 0.1 NaN NaN NaN
AlhamaDeMurciaS4 WC94-A 25 70 12 0.07 0.1 NaN NaN NaN
AlhamaDeMurciaC WC94-A 87 70 12 0.24 1.0 NaN NaN NaN
```

MB tool

What does it do?

For each fault, up to five Mmax values (and their errors) are computed:

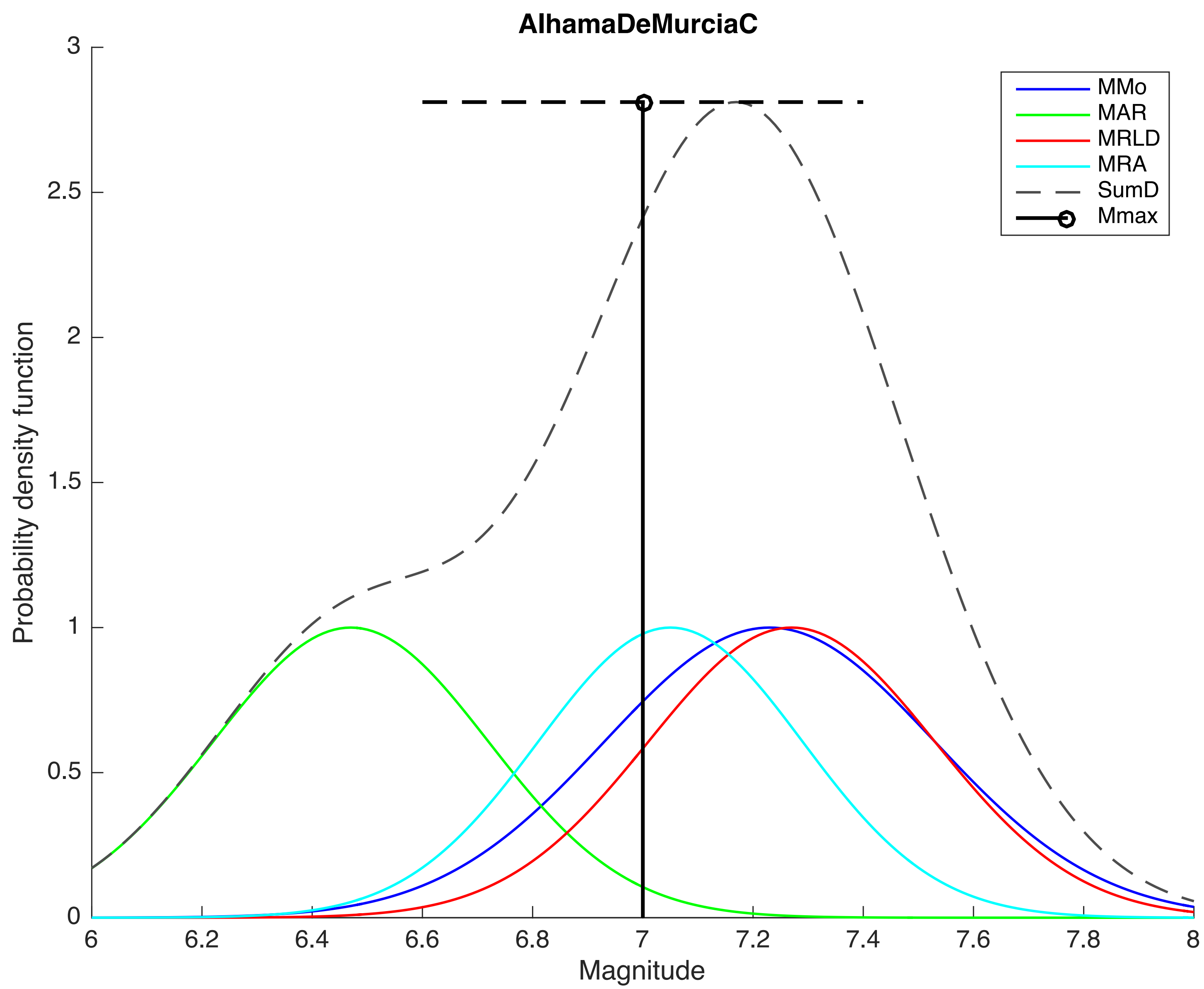
1. A magnitude value MM_0 is directly computed by applying the standard formula $M_W = 2/3 (\log M_0 - 9.1)$ (IASPEI, 2005)

2. A value of magnitude (M_{ASP}) is computed by modifing the along-strike dimension **if it exceeds** the length that is predicted by the aspect ratio relationships (Peruzza and Pace, 2002)

3. Two magnitude values that depend on the choice of the scale relationship are calculated.

4. A value that corresponds to the maximum observed magnitude (Mobs), if available

MB tool



To combine the maximum magnitudes, MB **draws** a probability curve for each magnitude estimate by assuming a normal distribution and then **sums** the probability density curves and fits the summed curve to a normal distribution to obtain **the mean** of the maximum magnitude and its standard deviation

***<u>Mmax</u>* = 7.0 +/- 0.4**

MB tool

Output .txt file by MB Tool

madrid_MB.txt

```
id Mmax sdMmax Tmean CV Telap Mo-rate name
1 6.5 0.2 1103 0.77 NaN 6.4184e+15 AlhamaDeMurciaS1
2 6.4 0.2 1006 0.88 NaN 4.9820e+15 AlhamaDeMurciaS2
3 6.1 0.3 4551 1.05 NaN 3.9074e+14 AlhamaDeMurciaS3
4 6.5 0.2 9730 0.71 NaN 7.2759e+14 AlhamaDeMurciaS4
5 7.0 0.4 7502 1.51 NaN 5.3067e+15 AlhamaDeMurciaC
```

Tmean = mean recurrence time of Mmax, given by the criterion of "segment seismic moment conservation" that was proposed by Field et al., 1999, which divides the seismic moment that corresponds to Mmax by the moment rate given a slip rate

$$T_{\text{mean}} = \frac{1}{\text{Char\_Rate}} = \frac{10^{1.5M_{\max}9.1}}{\mu VLW}$$

CV = Coefficient of Variation, standard deviation of the recurrence times over their mean

Mo-rate (N * m * yr^-1) = the ratio between the seismic moment, that corresponds to Mmax, and Tmean

RP tool

Why?

Mean and standard deviation of the recurrence times **can be derived from paleoseismological or historical earthquake** time series by considering the uncertainties in dating.

How?

Starting from an **input file** that contains the youngest and oldest years of occurence for each event in the series, **RP produces *n* simulations of the earthquake catalogue** using a uniform distribution for the occurrences within its window of uncertainty.

For each simulation **RP estimates** the arithmetic mean of the recurrence times and its standard deviation. RP also fits each simulation using three probability function (BPT, Weibull, Poisson)

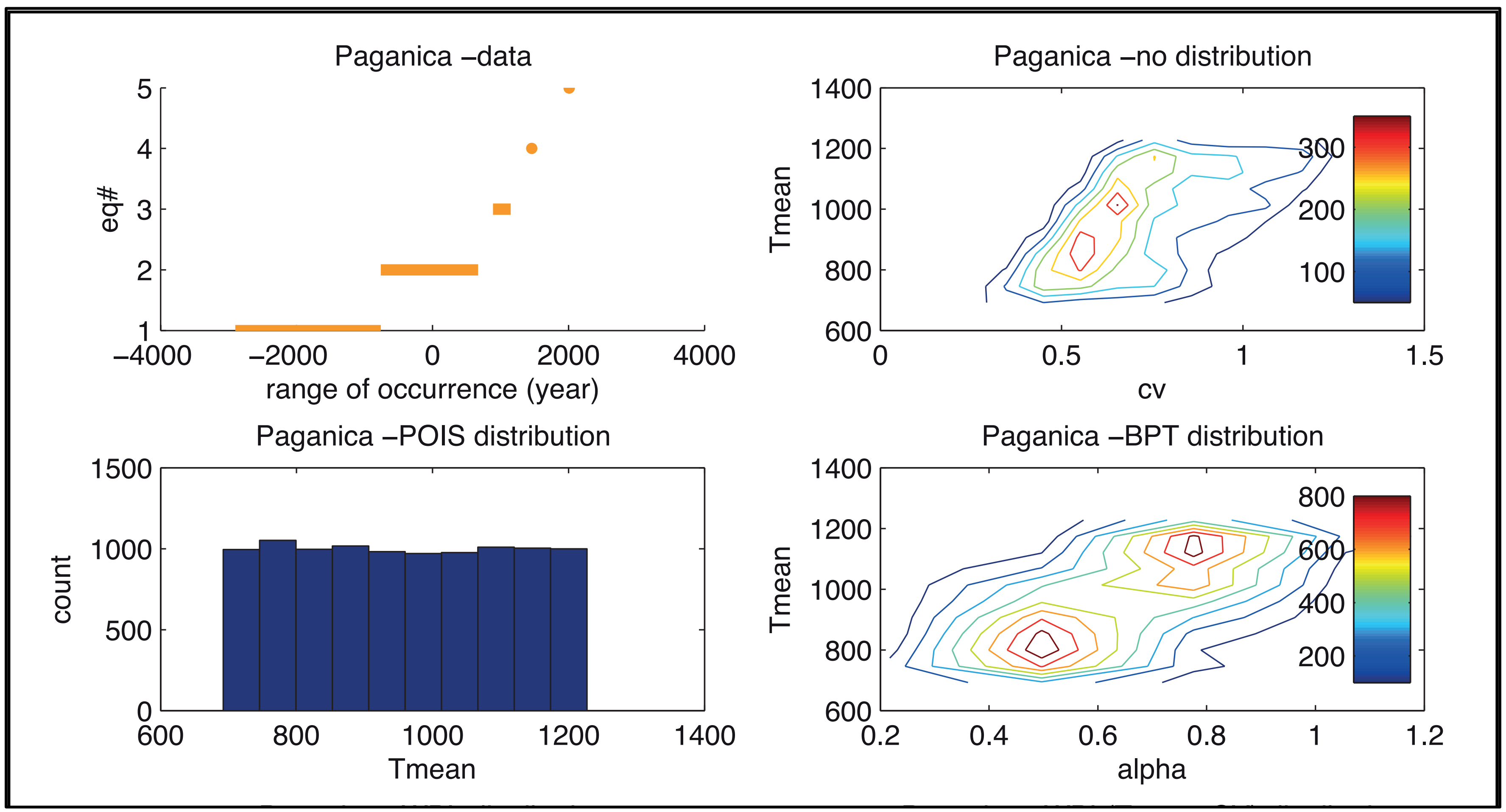
Input file format (filename.txt)	Paganica	
	oldest	**youngest**
Input file format (Paganica.paleo)	2009	2009
	1461	1461
	890	1150
	-760	670
	-2900	-760

RP tool

Two output from RP

Output file format	ARITH:	CV=0.65	Tmean=1013	BPT param:	alpha=0.50	Tmean=799	WBL param:	b=1.27	a=1233	b=1.27

WBL param (CV,Tmean)	CV=0.53	Tmean=1021	POIS param:	Tmean=1013	Paganica



The pairs of Tmean and CV that are obtained by RP can be entered into the AR tool depending on the user’s need.

AR tool

AR is designed to return **<u>annual earthquake rates.</u>** AR balances the annual earthquake rates over the range of magnitudes for the MFD with the moment rate.

Output .txt file from MB Tool is the **Input** file for AR

madrid_MB.txt

```
id Mmax sdMmax Tmean CV Telap Mo-rate name
1 6.5 0.2 1103 0.77 NaN 6.4184e+15 AlhamaDeMurciaS1
2 6.4 0.2 1006 0.88 NaN 4.9820e+15 AlhamaDeMurciaS2
3 6.1 0.3 4551 1.05 NaN 3.9074e+14 AlhamaDeMurciaS3
4 6.5 0.2 9730 0.71 NaN 7.2759e+14 AlhamaDeMurciaS4
5 7.0 0.4 7502 1.51 NaN 5.3067e+15 AlhamaDeMurciaC
```

The **<u>basic information for modeling Gutenberg-Richter</u>** MFDs, that is, the minimum magnitude and b-value, is handled separtely in a **<u>second input file</u>**.

AR tool

Before to run AR Tool, the user has to choose the MFD, among these:

- ➢ *Single-Value Model (Poisson)*
- ➢ *Single-Value Model (BPT)*
- ➢ *Single-Value Model (User-Defined Probability)*

- ◆ *Characteristic Gaussian Model (Poisson)*
- ◆ *Characteristic Gaussian Model (BPT)*
- ◆ *Characteristic Gaussian Model (User-Defined Probability)*

- ❑ *Classical Gutenberg-Richter*
- ❑ *Truncated Gutenberg-Richter*

AR tool

Two outputs .txt file by AR Tool

-Rates

madrid_AR_SinglePoisson_rates.txt

```
id Mchar rate name
1, 6.5, 9.066e-04, AlhamaDeMurciaS1
2, 6.4, 9.940e-04, AlhamaDeMurciaS2
3, 6.1, 2.197e-04, AlhamaDeMurciaS3
4, 6.5, 1.028e-04, AlhamaDeMurciaS4
5, 7.0, 1.333e-04, AlhamaDeMurciaC
```

madrid_AR_ChGaussPoisson_rates.txt

```
id Mmin bin rates name
1, 6.3, 0.1, 1.2539e-04 1.8244e-04 2.0673e-04 1.8244e-04 1.2539e-04 , AlhamaDeMurciaS1
2, 6.2, 0.1, 1.3748e-04 2.0003e-04 2.2667e-04 2.0003e-04 1.3748e-04 , AlhamaDeMurciaS2
3, 5.8, 0.1, 1.9233e-05 2.5391e-05 2.9996e-05 3.1709e-05 2.9996e-05 2.5391e-05 1.9233e-05 , AlhamaDeMurciaS3
4, 6.3, 0.1, 1.4214e-05 2.0681e-05 2.3435e-05 2.0681e-05 1.4214e-05 , AlhamaDeMurciaS4
5, 6.6, 0.1, 7.9104e-06 9.8447e-06 1.1510e-05 1.2641e-05 1.3042e-05 1.2641e-05 1.1510e-05 9.8447e-06 7.9104e-06 , AlhamaDeMurciaC
```

madrid_AR_SinglePoisson_Probability.txt

```
id Mchar window Probability name
1, 6.5, 50, 4.432e-02, AlhamaDeMurciaS1
2, 6.4, 50, 4.849e-02, AlhamaDeMurciaS2
3, 6.1, 50, 1.093e-02, AlhamaDeMurciaS3
4, 6.5, 50, 5.126e-03, AlhamaDeMurciaS4
5, 7.0, 50, 6.643e-03, AlhamaDeMurciaC
```

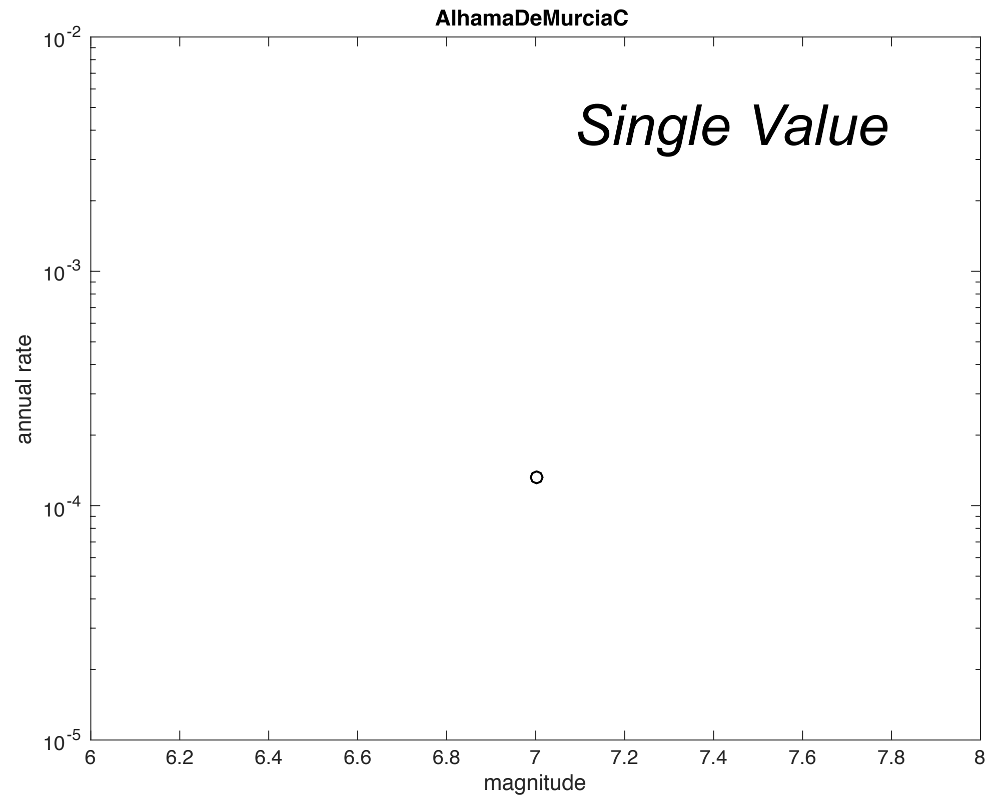
madrid_AR_ChGaussPoisson_Probability.txt

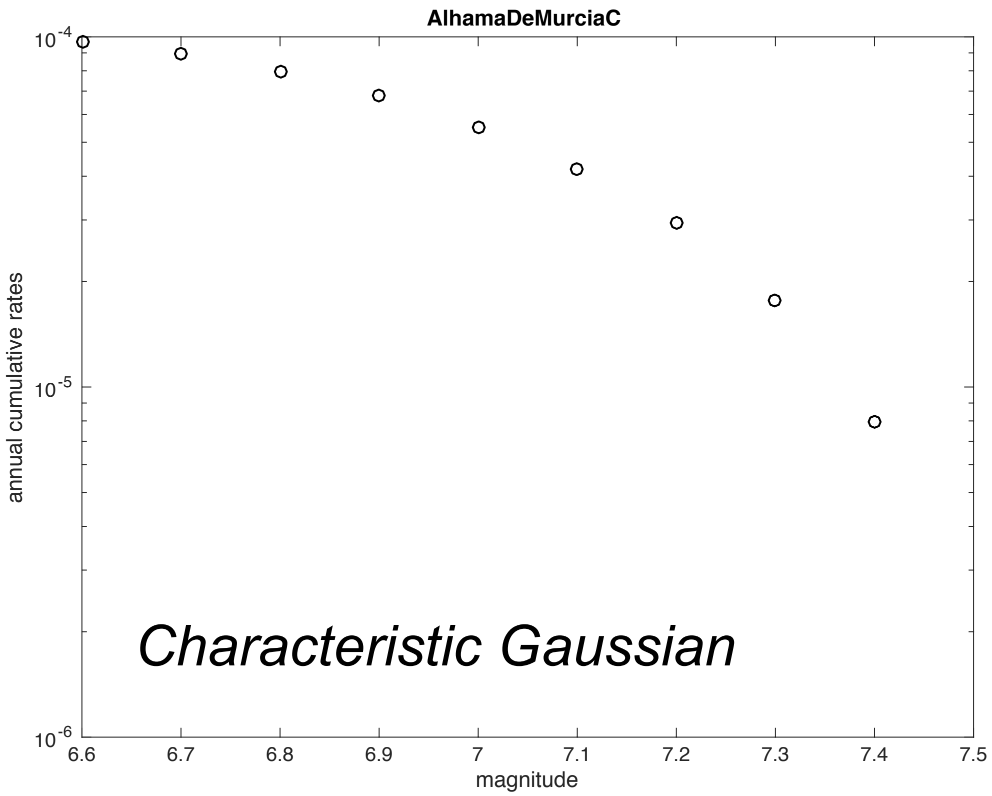
```
id Mmin window Probability name
1, 6.3, 50, 4.029e-02, AlhamaDeMurciaS1
2, 6.2, 50, 4.408e-02, AlhamaDeMurciaS2
3, 5.8, 50, 9.007e-03, AlhamaDeMurciaS3
4, 6.3, 50, 4.650e-03, AlhamaDeMurciaS4
5, 6.6, 50, 4.831e-03, AlhamaDeMurciaC
```

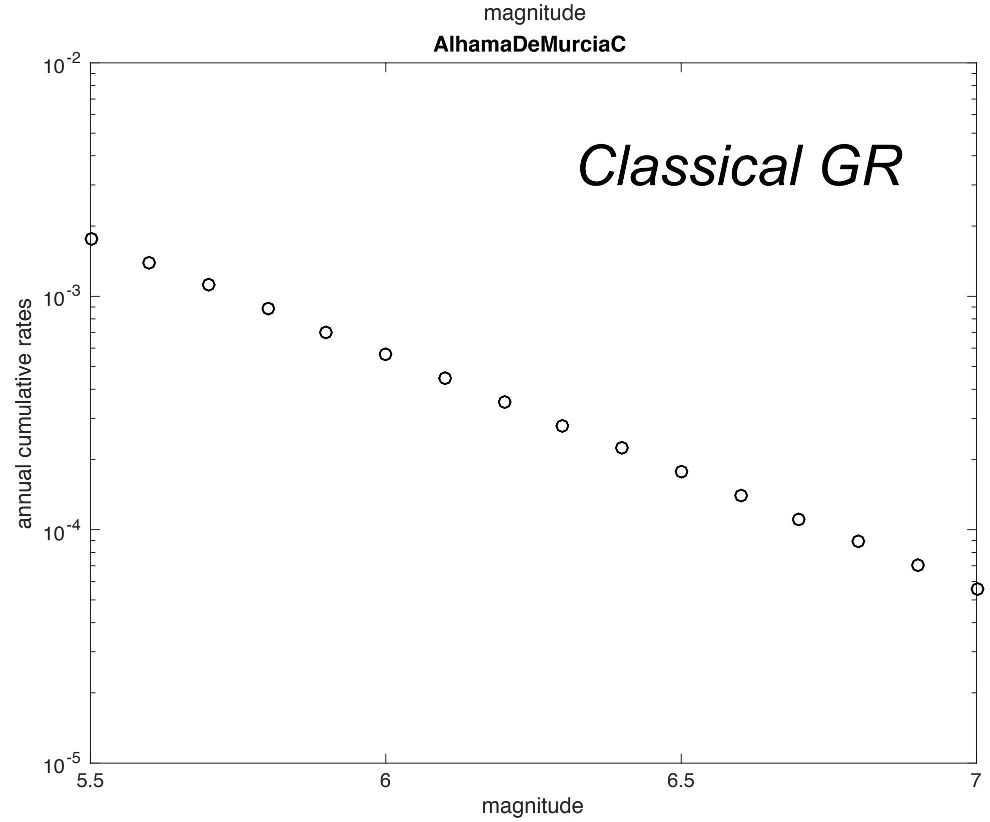
-Probability

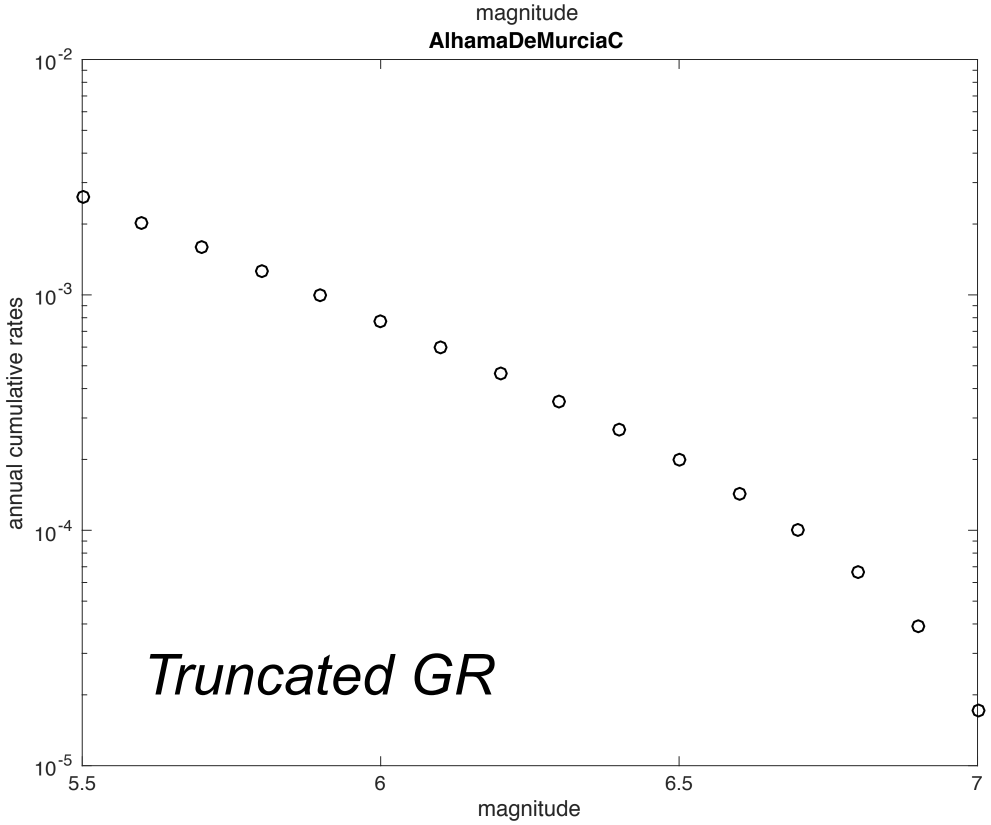
AR tool

.eps output file with the rates for each fault



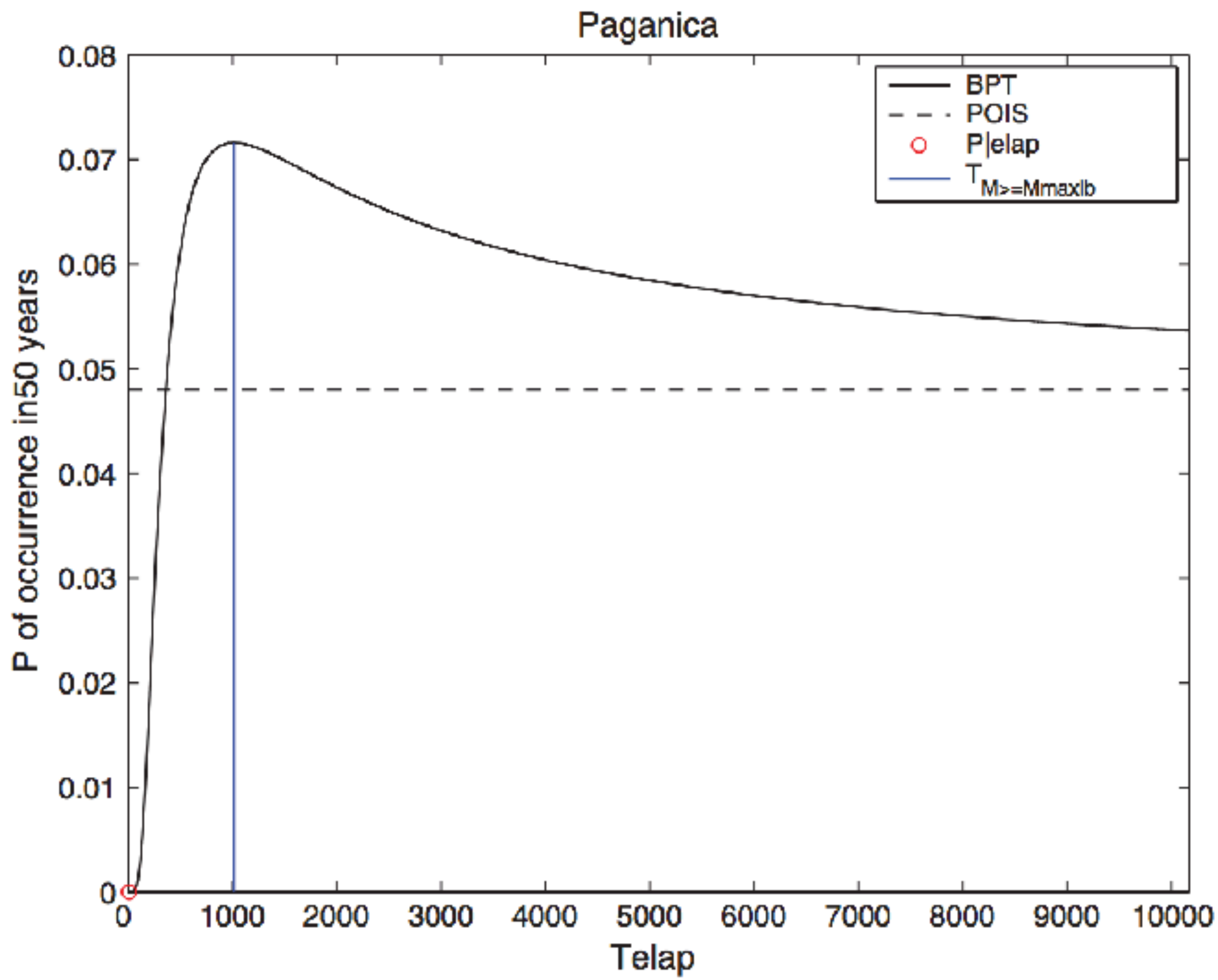






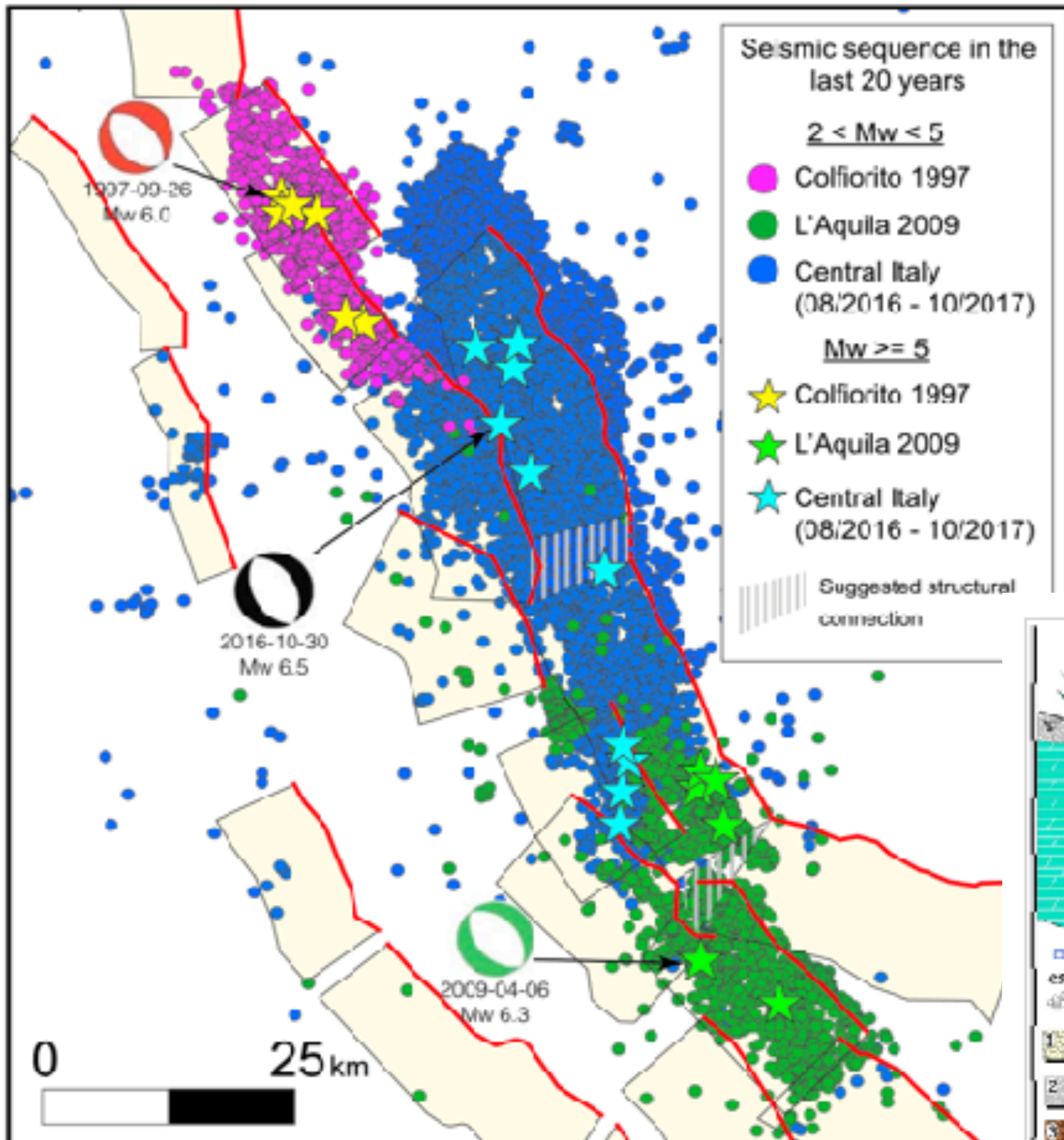
AR tool

.eps output file with the probabilities for each fault

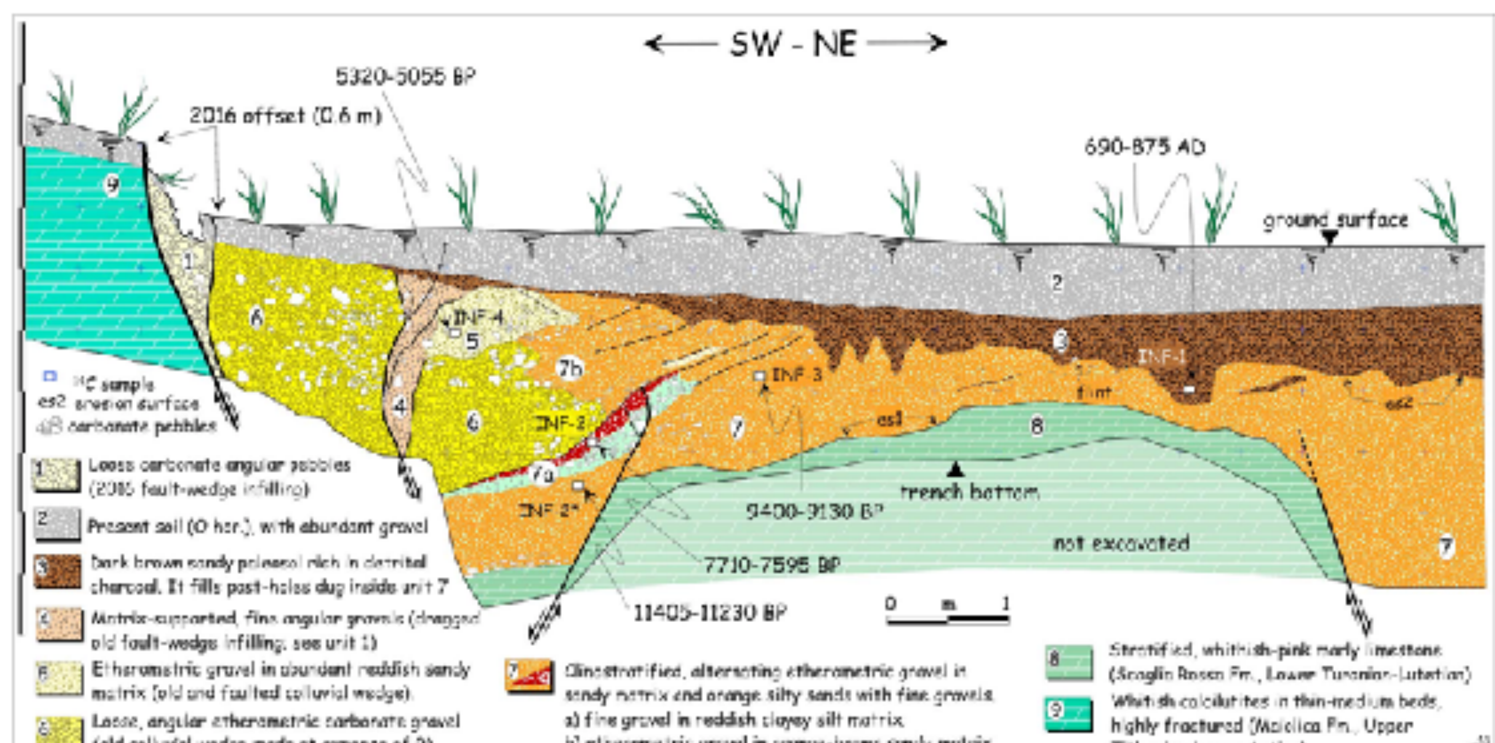


Assumptions and consequences

The 2016 Central Italy seismic sequence

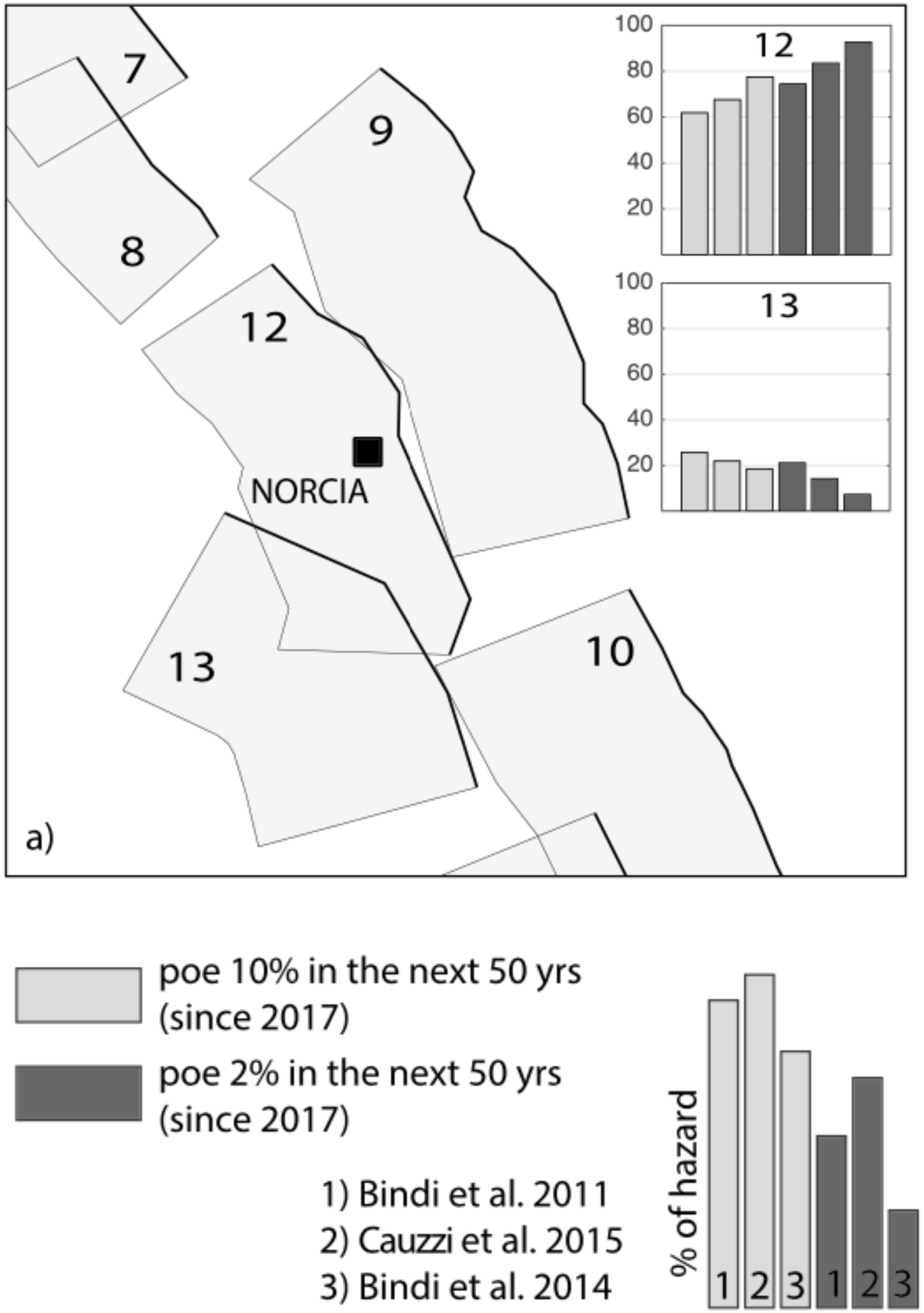


Valentini et al. 2019 Tectonics



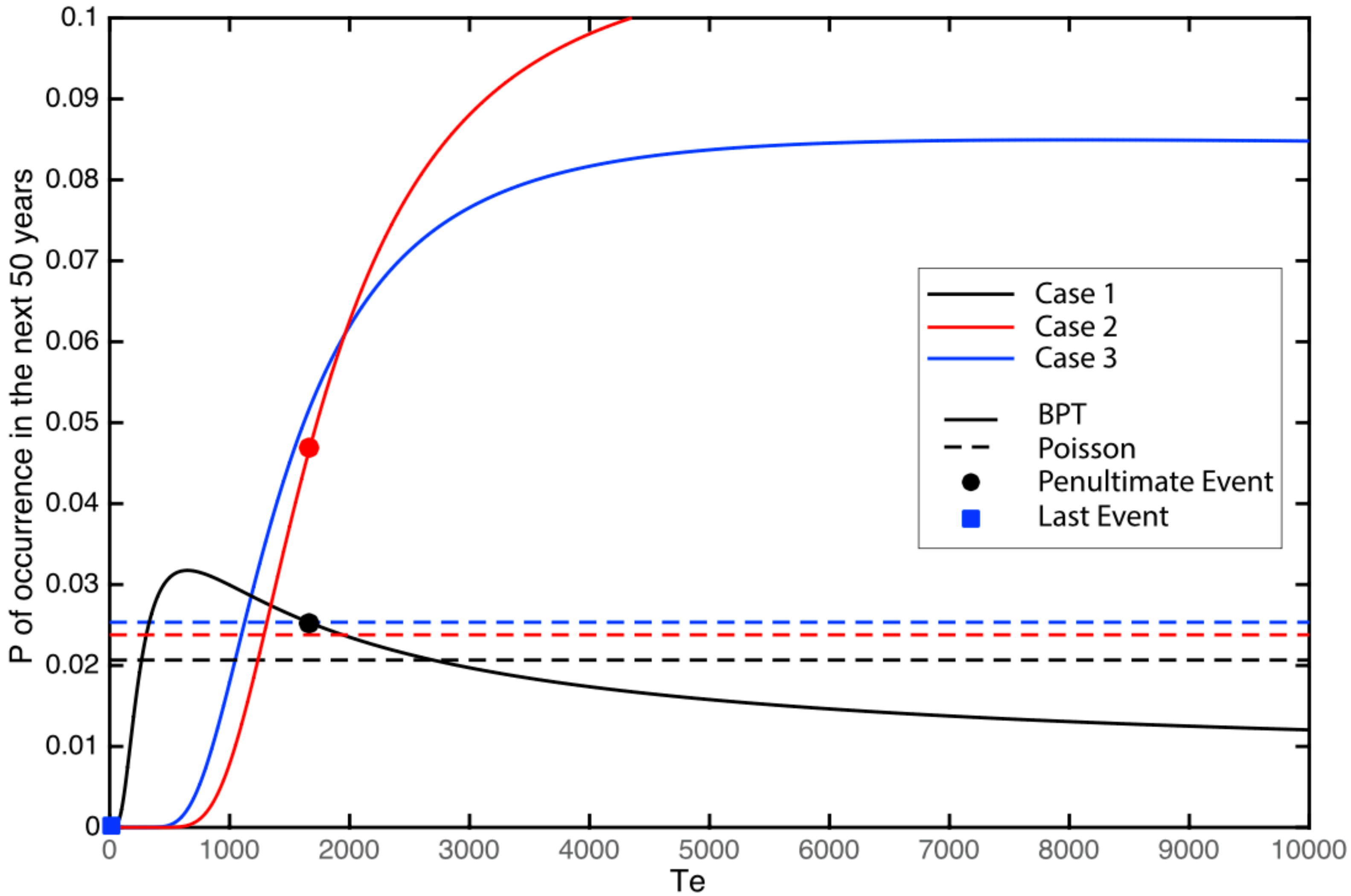
Galli et al. 2019 Tectonics

Assumptions and consequences



3 cases: (1) before the 2016 seismic sequence, (2) before the seismic sequence with the new(post 2016) knowledge, and (3) after the seismic sequence. In the first case, we used old geometrical and kinematical parameters (length, seismogenic thickness, rake, and long-term slip rate), to compute the activity rates for the two ISSs involved in the 2016 sequence. Being a time-dependent approach a key role is played by the time elapsed since the last event. In the first two cases the last event occurred on the Bove-Vettore source ~1,700 years ago, whereas in the last case the elapsed time is only 1 year. Moreover, in Cases 2 and 3, we used new data acquired after the sequence, in particular the new paleoseismological data collected on the fault, to understand how a good knowledge of a fault seismic history impacts the hazard estimation.

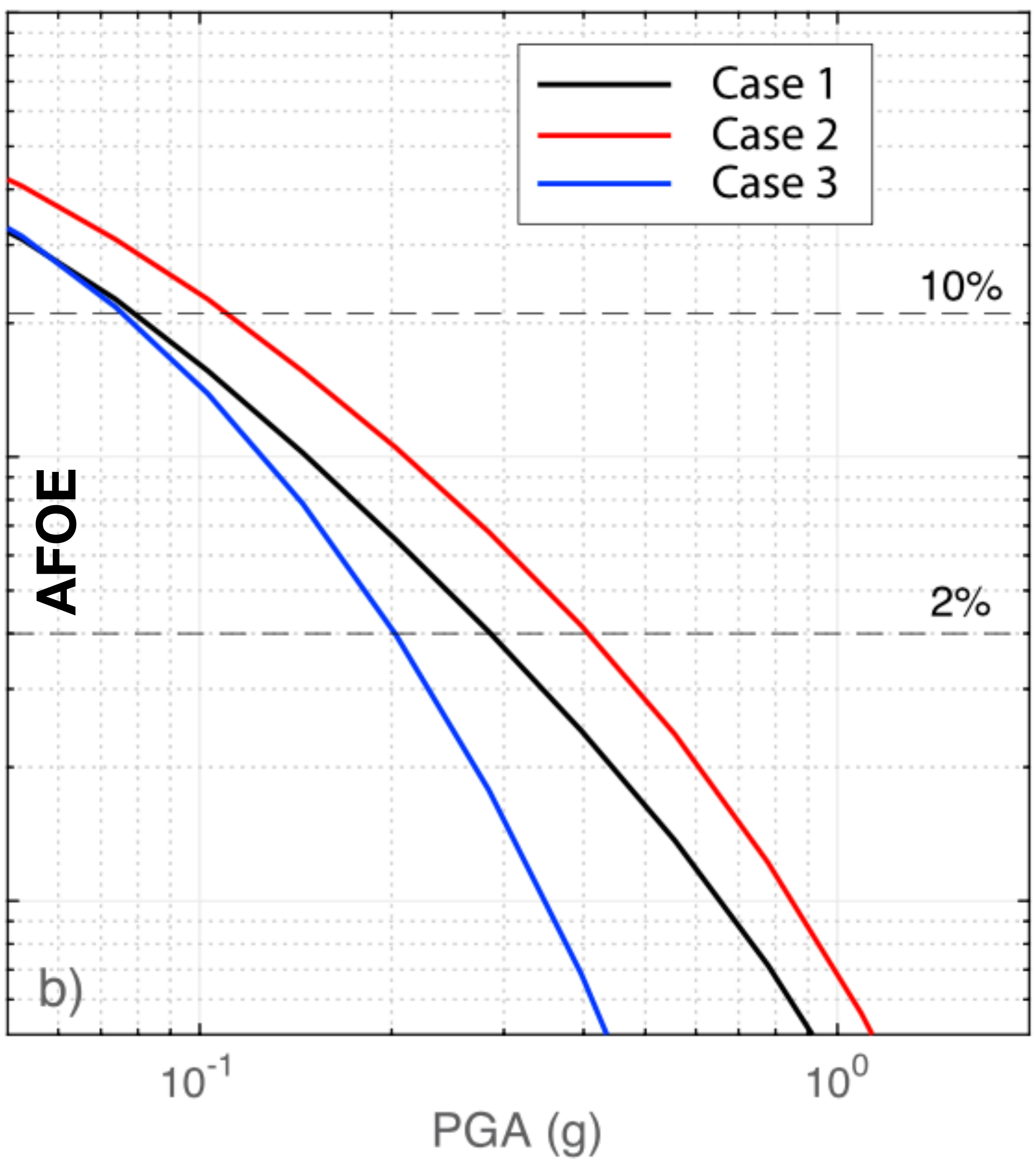
Assumptions and consequences



BPT and Poissonian probability curves versus elapsed time (Te) calculated for the Bove-Vettore ISS9 for the 3 cases explored. Case (1) geometrical/kinematic parametrization of the source before the 2016 sequence (Tmean = 1971; CoV = 1.24); (2) use of paleoseismological data, excluding the 2016 event (Tmean = 1710; CoV = 0.33); (3) as (2) but including the last event (Tmean = 1604; CoV = 0.39).

BPT = Brownian Passage Time; CoV = coefficient of variation.

Assumptions and consequences



PGA hazard curves computed at Norcia considering only the two ISSs (9 and 10) involved in the 2016 seismic sequence and the 3 cases.

The figure shows clearly how modification of the parameter of the sources can impact on the seismic hazard estimation. The figure shows also that in a fault-based PSHA, the time- dependent approach can play a key role in the hazard estimation. In the third case, where the elapsed time from the last earthquake is 1 year for ISS 9-Bove-Vettore, the hazard curve shows the lowest values as it is actually controlled mainly by the ISS 10-Gorzano.

- With FiSH our intent was to distribute tools that can help researchers to pinpoint potential inconsistencies and obtain more reliable fault-based seismic hazard evaluations.

  A fault-based and time-dependent approaches give a complementary view of PSHA with respect to zone-based and Poisson ones, especially in terms of spatial resolution and extension of the observational time required to capture the recurrence of large-magnitude events, improving the reliability of seismic hazard assessments.

In a fault-based and time-dependent approaches, improving the knowledge of the seismogenic sources, regarding geometry, kinematics, seismic history, and seismogenic potential can have a large impact to final results. To this aim, we need to encourage collecting and analyzing new geological data on active faults.

THANK YOU AND SEE YOU TO THE HANDS ON SESSION!