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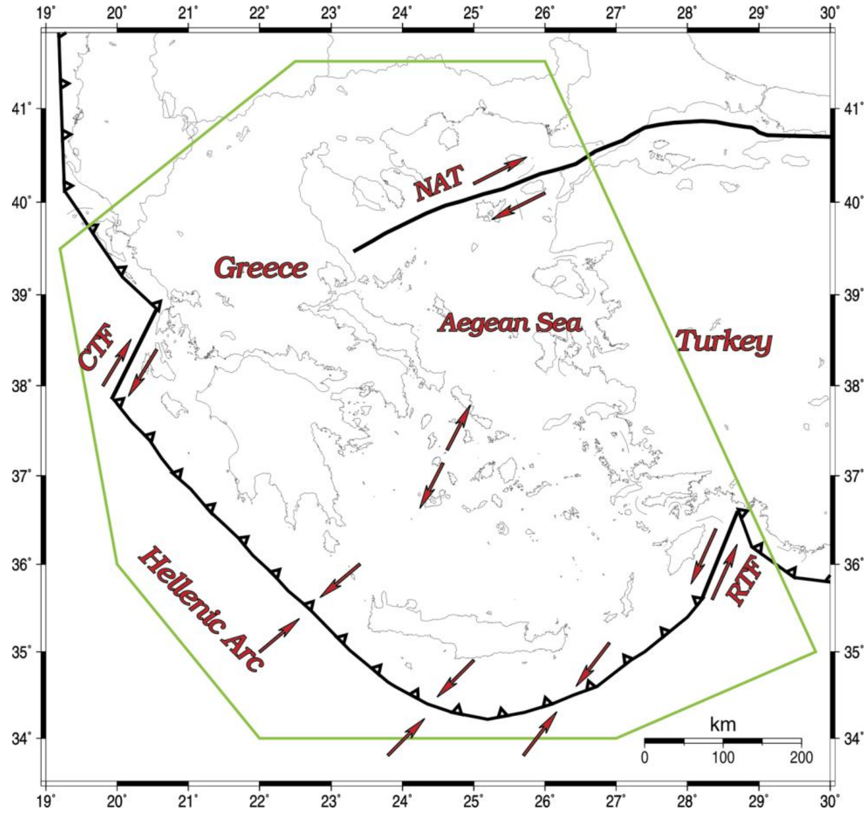
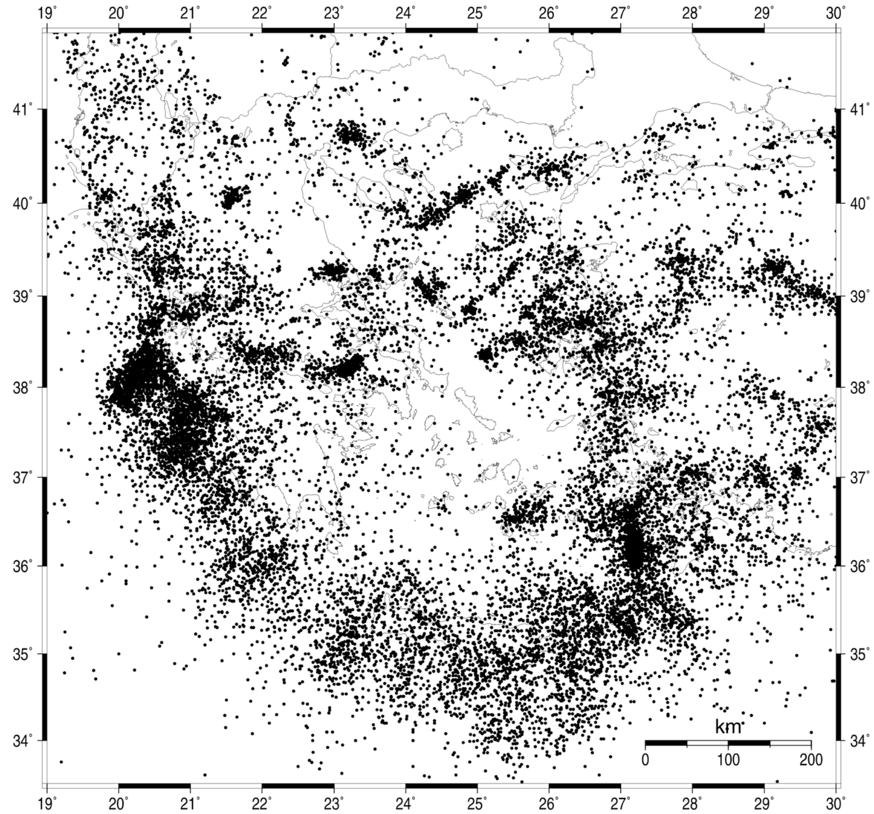
Renewal models and co-seismic stress transfer in the Corinth Gulf, Greece, fault system

Statsei7 meeting

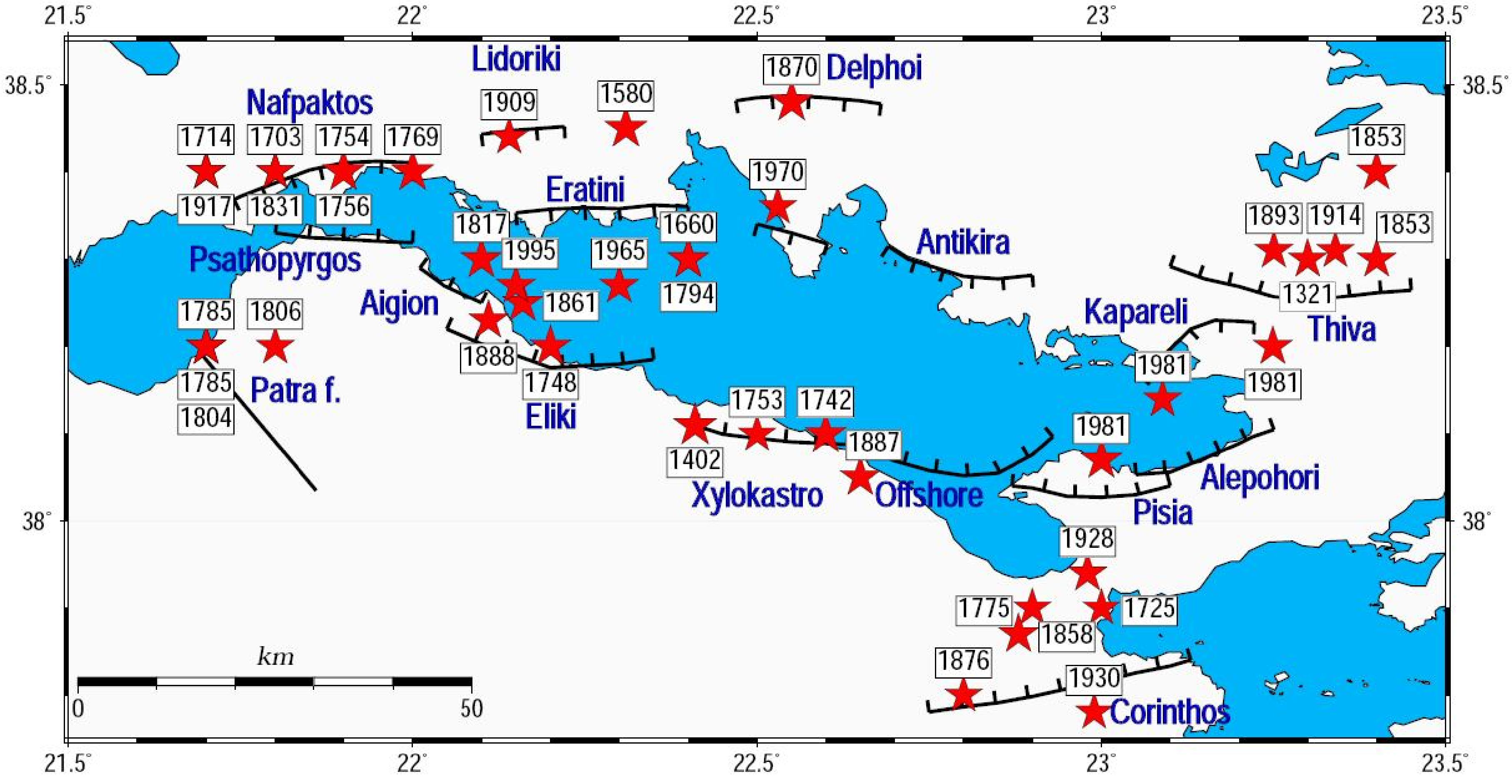
Santorini, Greece, 25-27 May 2011

Tectonics and seismicity of Greece





The Gulf of Corinth has long been recognized as one of the most active rifts in the highly seismic Aegean. Its quaternary normal faulting, its high level of seismicity, and the 1 cm/yr overall N–S geodetic extension rate, makes it a key place within the Mediterranean area to study the physical processes related to the seismic cycle.



April 22, 1928
Xilokastro Eq.
macroseismic
Information
(Ambraseys and
Jackson, 1990)

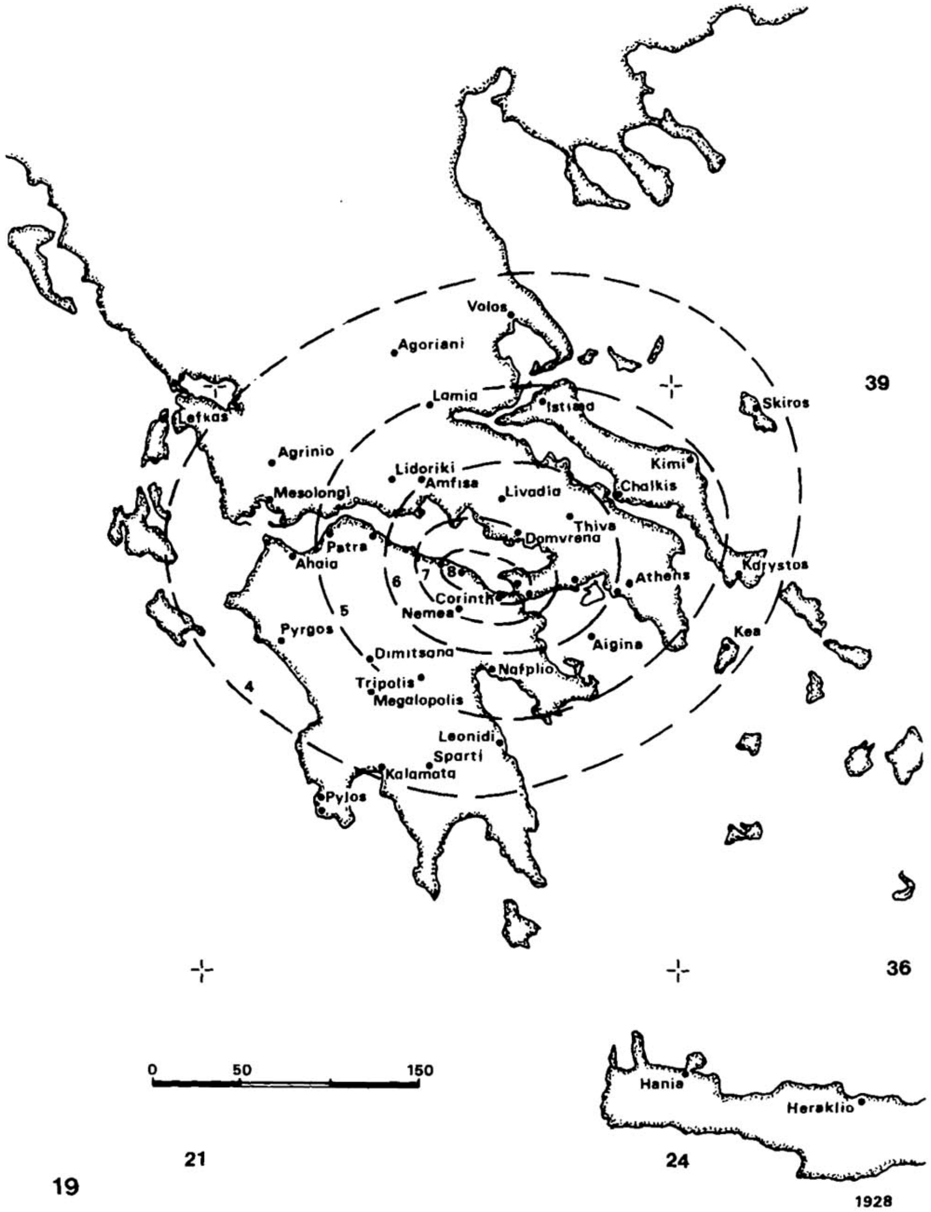
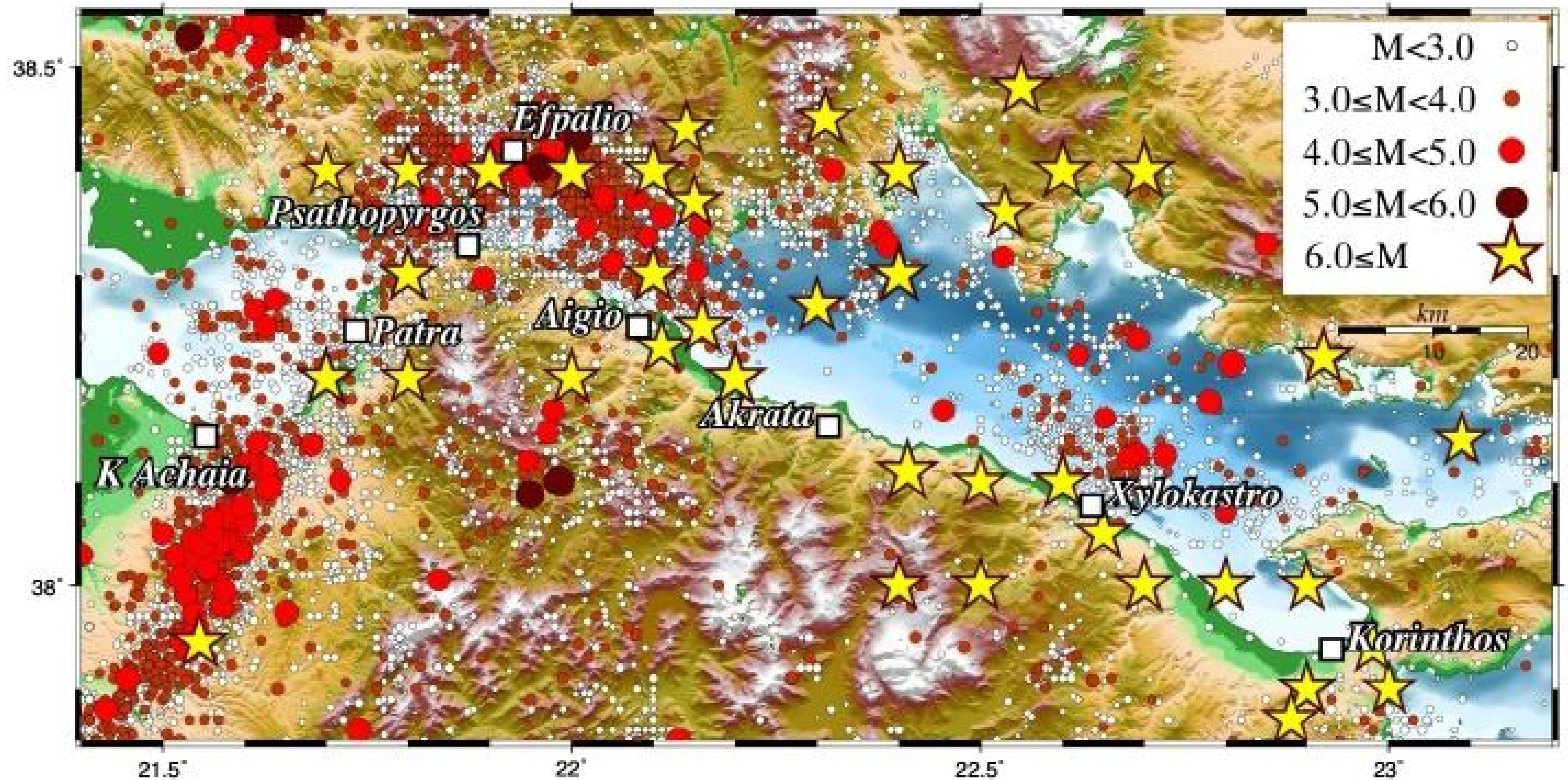


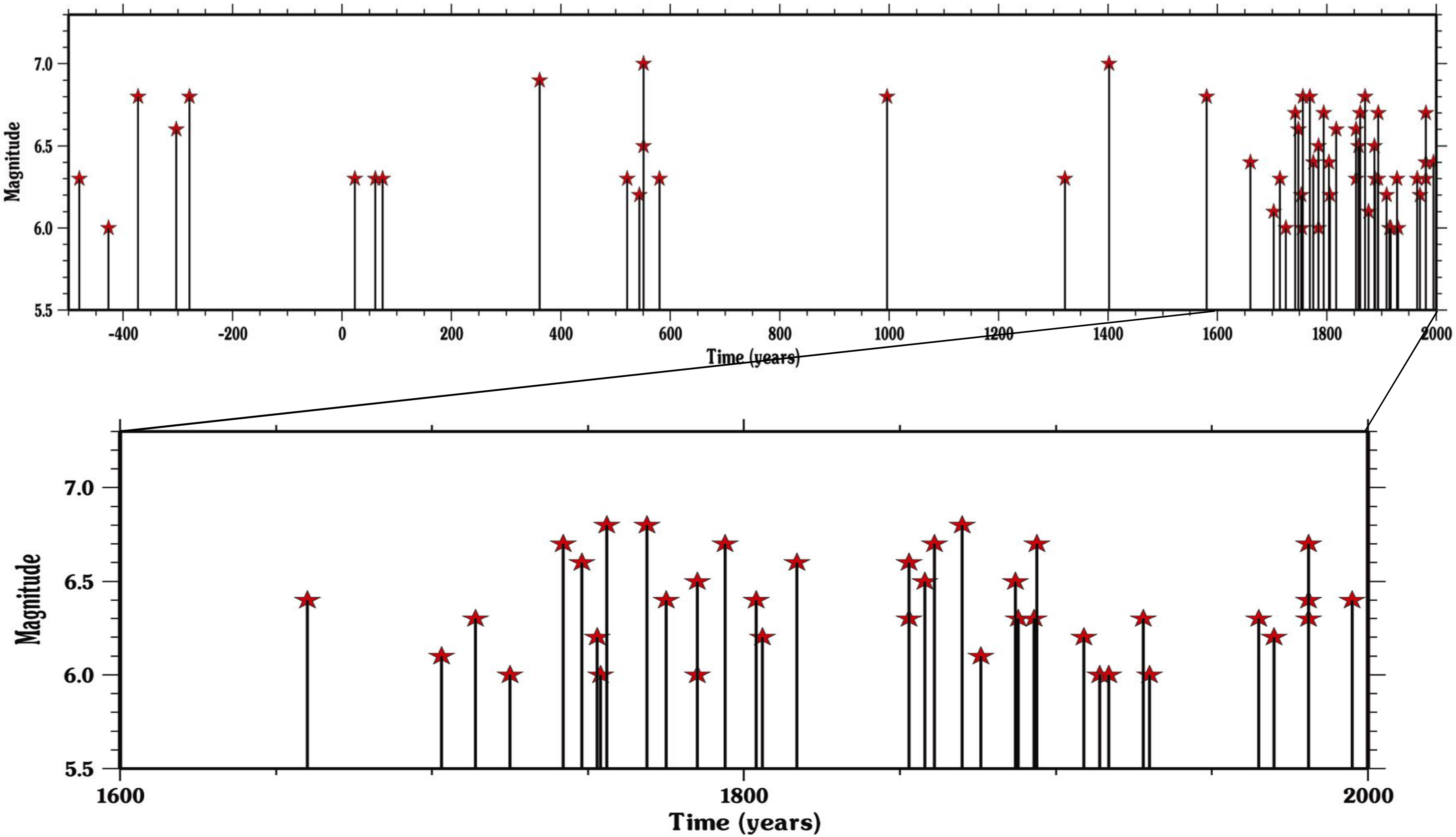
Figure A19. 1928 April 22; Corinth earthquake (M_s 6.3).

Seismicity map of all the known historical and instrumental earthquakes with M≥6.0, along with the epicenters of all the earthquakes since 2008, recorded by the permanent national seismological network.

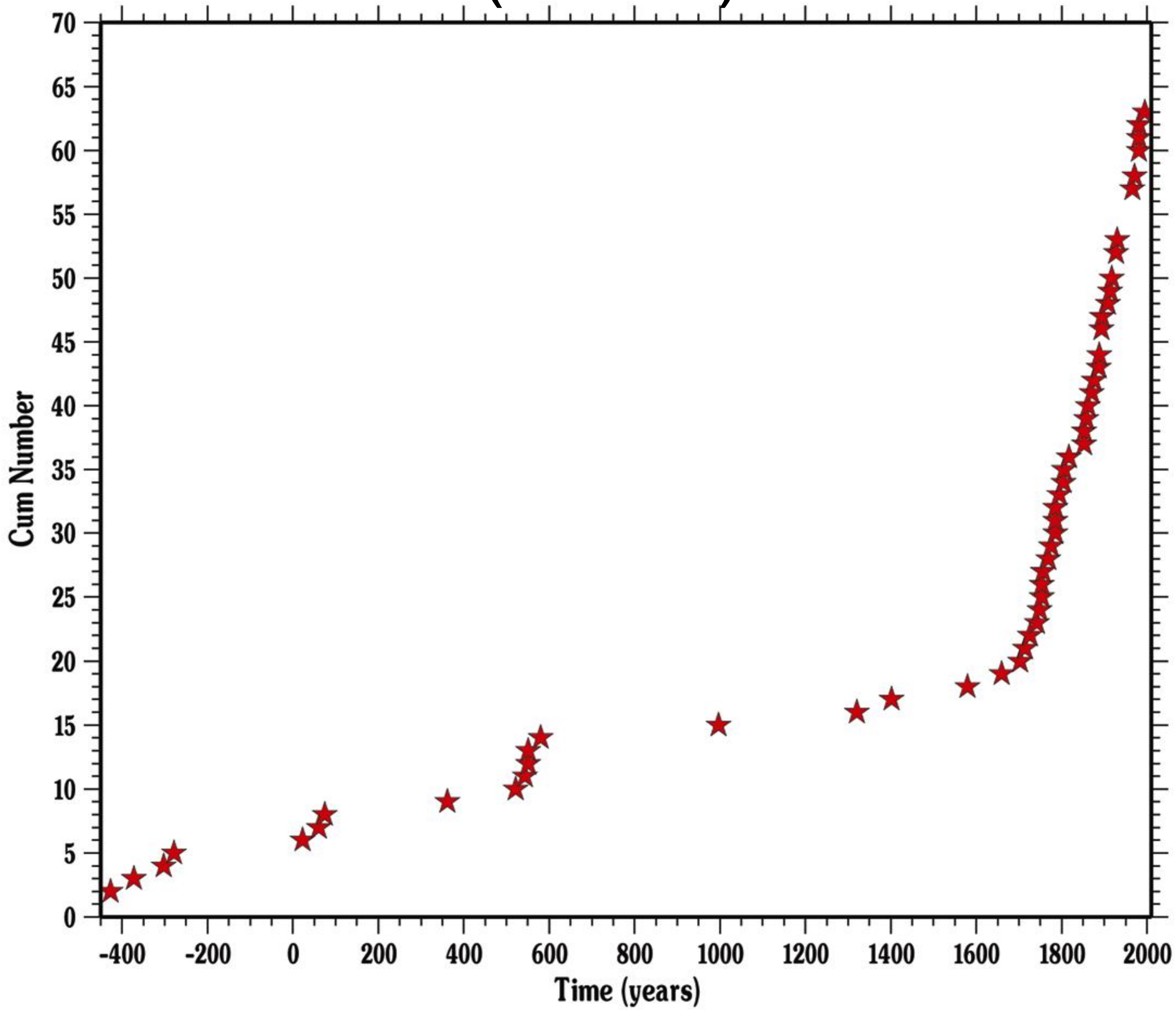
(Karakostas et al., 2010)



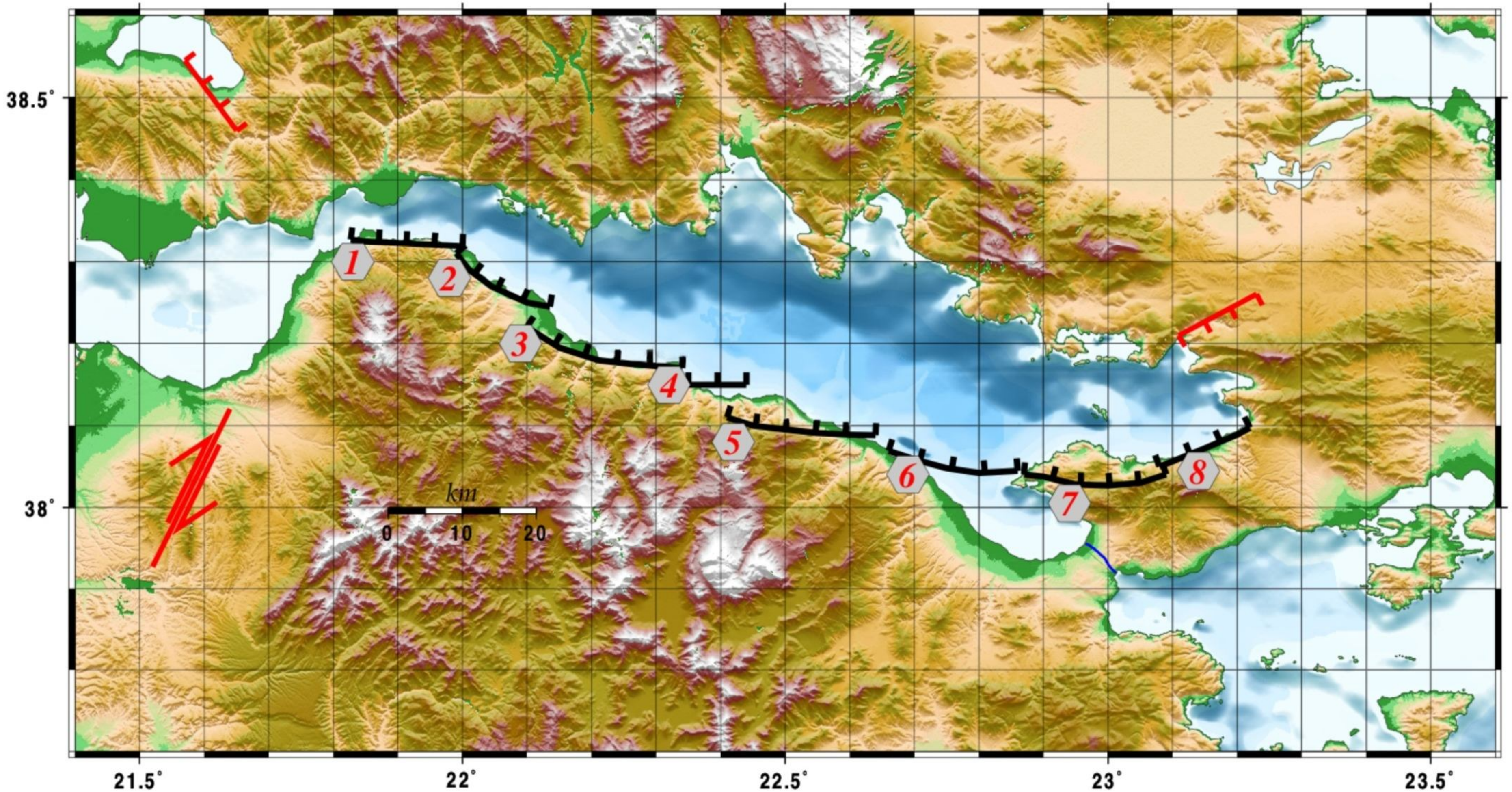
Seismicity of the Corinth Gulf area



Cumulative distribution of earthquakes (M≥6.0)

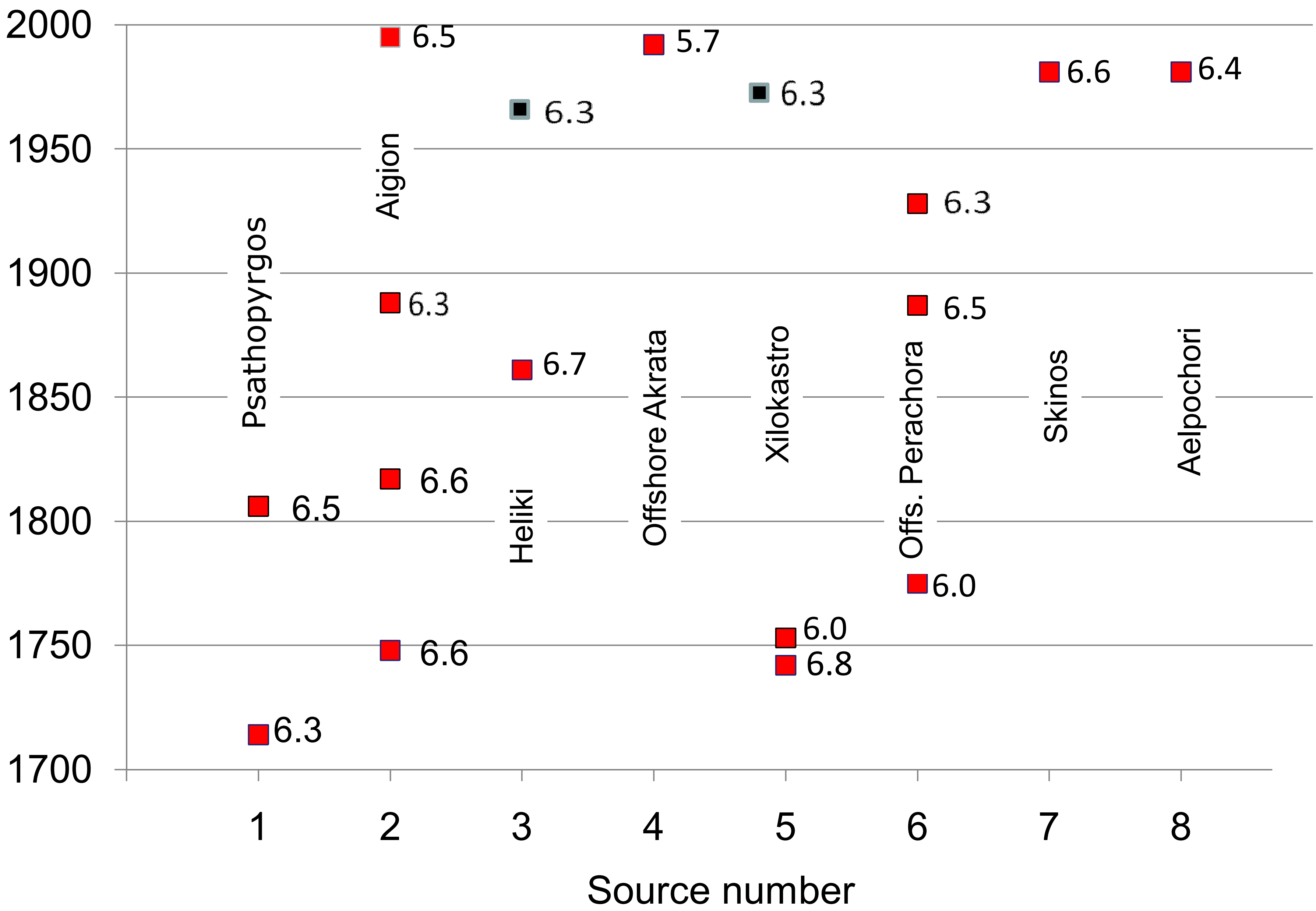


The Corinth Gulf fault system "adjusted" segmentation



Segment number	Segment name	Slip rate	Recurrence time
1	Psathopyrgos	6 mm/yr	126
2	Aigion	6 mm/yr	146
3	Heliki	6 mm/yr	260
4	Offshore Akrata	5 mm/yr	40
5	Xylokastro	5 mm/yr	252
6	Offshore Perachora	4 mm/yr	135
7	Skinos	3 mm/yr	319
8	Aelpochori	3 mm/yr	285

Characteristic earthquakes considered in this study



The faults are supposed to behave independently of each other according to a probability distribution of the inter-event times as described by the Brownian Passage Time (BPT) renewal model:

$$f(t;T_r,\alpha) = \left(\frac{T_r}{2\pi\alpha^2 t^3}\right)^{1/2} \exp\left\{-\frac{(t-T_r)^2}{2T_r\alpha^2 t}\right\}$$

An alternative inter-event time distribution tested in this study is the Weibull distribution:

$$f(t;T_r,\gamma)=\frac{\gamma}{T_r}\left(\frac{t}{T_r}\right)^{\gamma-1}\exp\left\{-\left(\frac{t}{T_r}\right)^{\gamma}\right\}$$

The probability of occurrence of a new event in a given time window Δt, conditional to the occurrence of no events before time *t*, is obtained from the density distribution of the recurrence times:

$$\Pr\left[t < T \le t + \Delta t \middle| \mathrm{T} > \mathrm{t}\right] = \frac{\Pr\left[t < T \le t + \Delta t\right]}{\Pr\left[t < T\right]} = \frac{\int_{t}^{t+\Delta t} f(u)du}{1 - \int_{0}^{t} f(u)du}$$

Theoretical basis

We compute the stress tensor change due to slip on a rectangular fault on the surrounding elastic environment.
The Coulomb stress change is a linear combination of the shear and normal stress:

$$\Delta CFF = \Delta\tau + \mu' \cdot \Delta\sigma_n$$

The computation of ΔCFF requires the knowledge of the focal mechanism of the impending earthquake on the triggered fault.

The time elapsed since the previous earthquake is modified by a shift proportional to ΔCFF:

$$t' = t + \frac{\Delta CFF}{\dot{\tau}}$$

where $\dot{\tau}$ is the tectonic stressing rate.

Alternatively, the stress change can be equivalent to a modification of the expected recurrence time:

$$T_r' = T_r - \frac{\Delta CFF}{\dot{\tau}}$$

Contingency table

Forecast	Observed Yes	Observed No
Yes	a	b
No	d	c

The ROC diagram is a plot where the X-axis (false alarm rate) is defined as

$F = b/(b+c)$ (fraction of alarms issued where an event has not occurred)

and the Y-axis (hit rate) is defined as

$H = a/(a+d)$ (fraction of events that occur on an alarm cell).

H depends on the probability threshold adopted for giving alarm.

The R-score is defined as the number of cells in which earthquakes are successfully predicted / the total number of cells containing alarms – the number of failures to predict / the total number of cells without any alarms:

$$R = a / (a+b) - d / (c+d)$$

(still function of the probability threshold adopted for giving an alarm).

The probability gain is the ratio between the conditional probability (success rate) and the unconditional probability (average occurrence rate):

$$G = a/(a+d) \cdot e/(a+b) = H \cdot e/(a+b)$$

(where $e = a+b+c+d$)

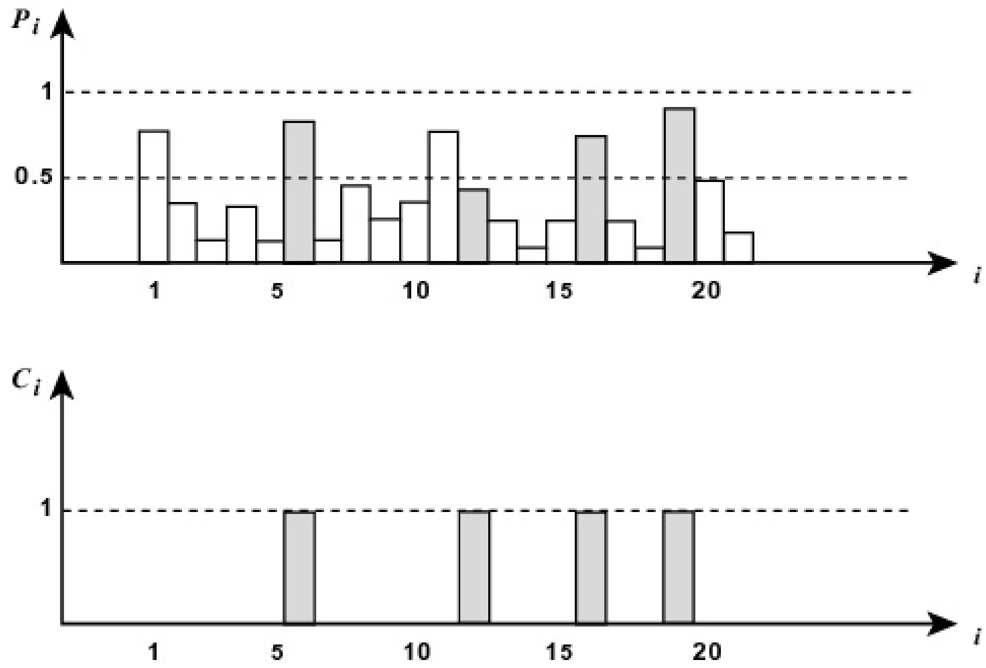
This is also function of the probability threshold adopted for giving an alarm.

Definition of the likelihood for the realization of a binomial process under a certain hypothesis

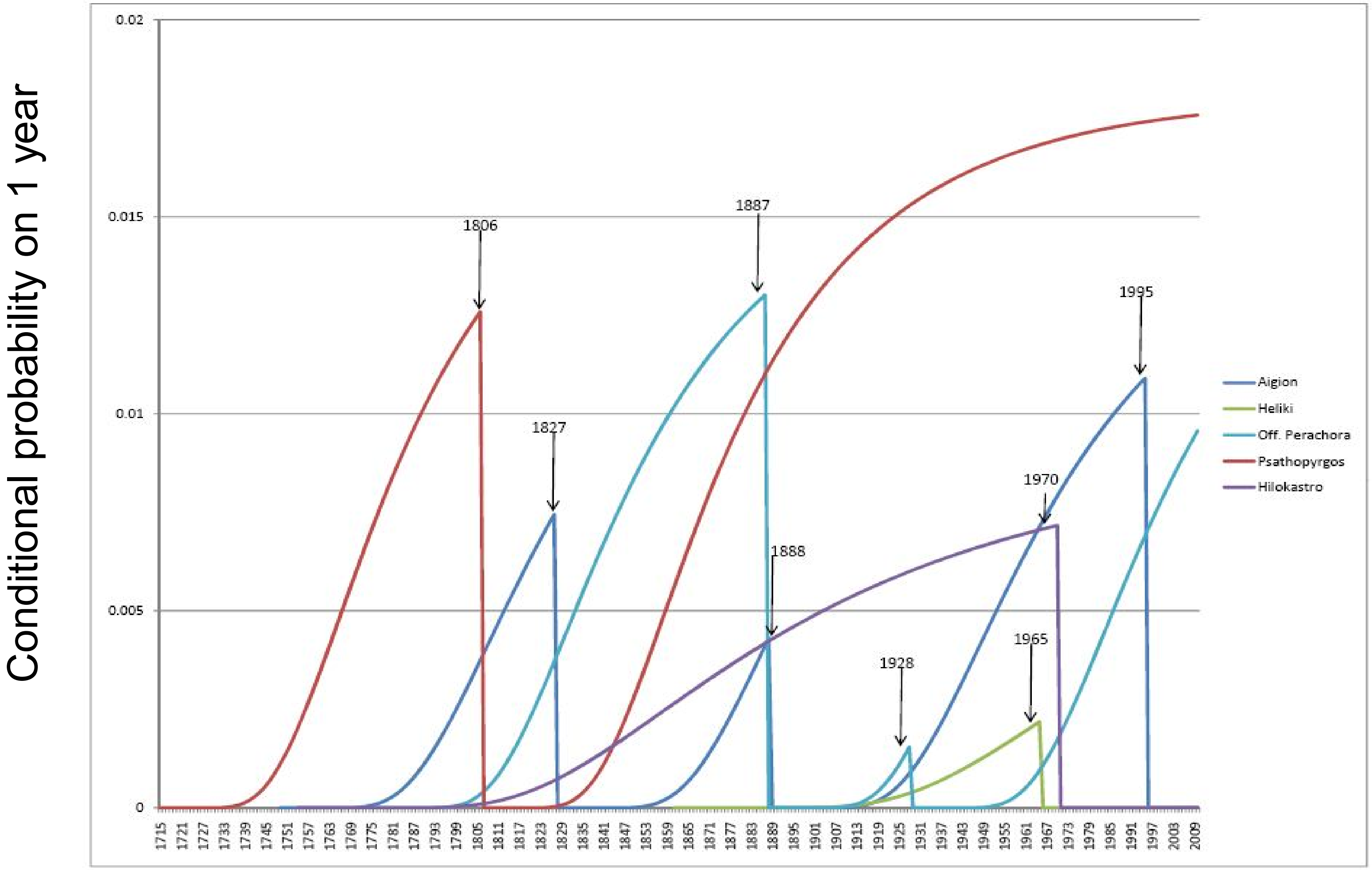
$$\log L = \sum_{i=1}^{P} \left[c_i \log(p_i) + (1 - c_i)\log(1 - p_i) \right]$$

p_i: probability associated to every cell in the space-time-magnitude volume

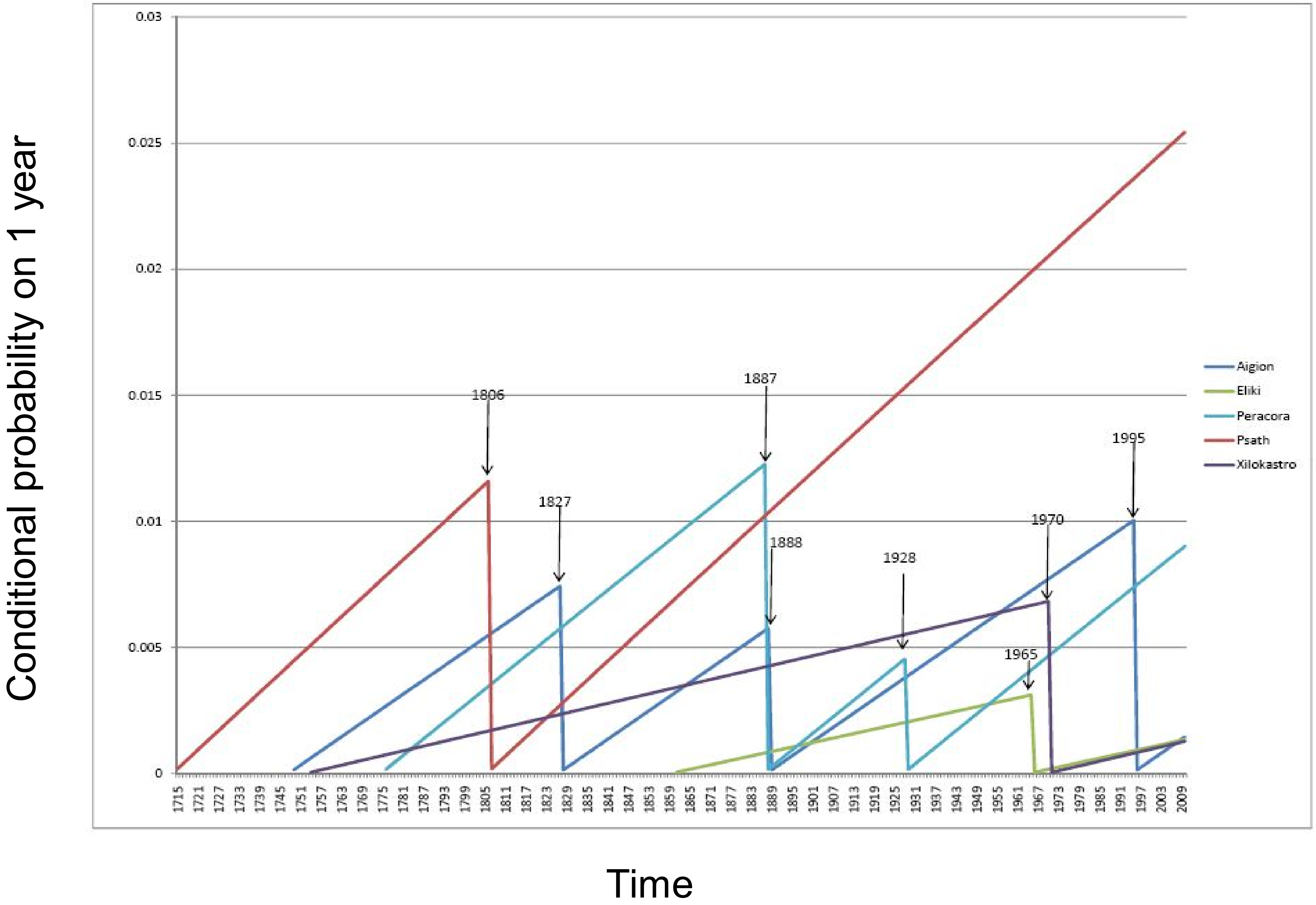
c_i: binary value of non-occurrence (0) or occurrence (1) of the event in the respective cell



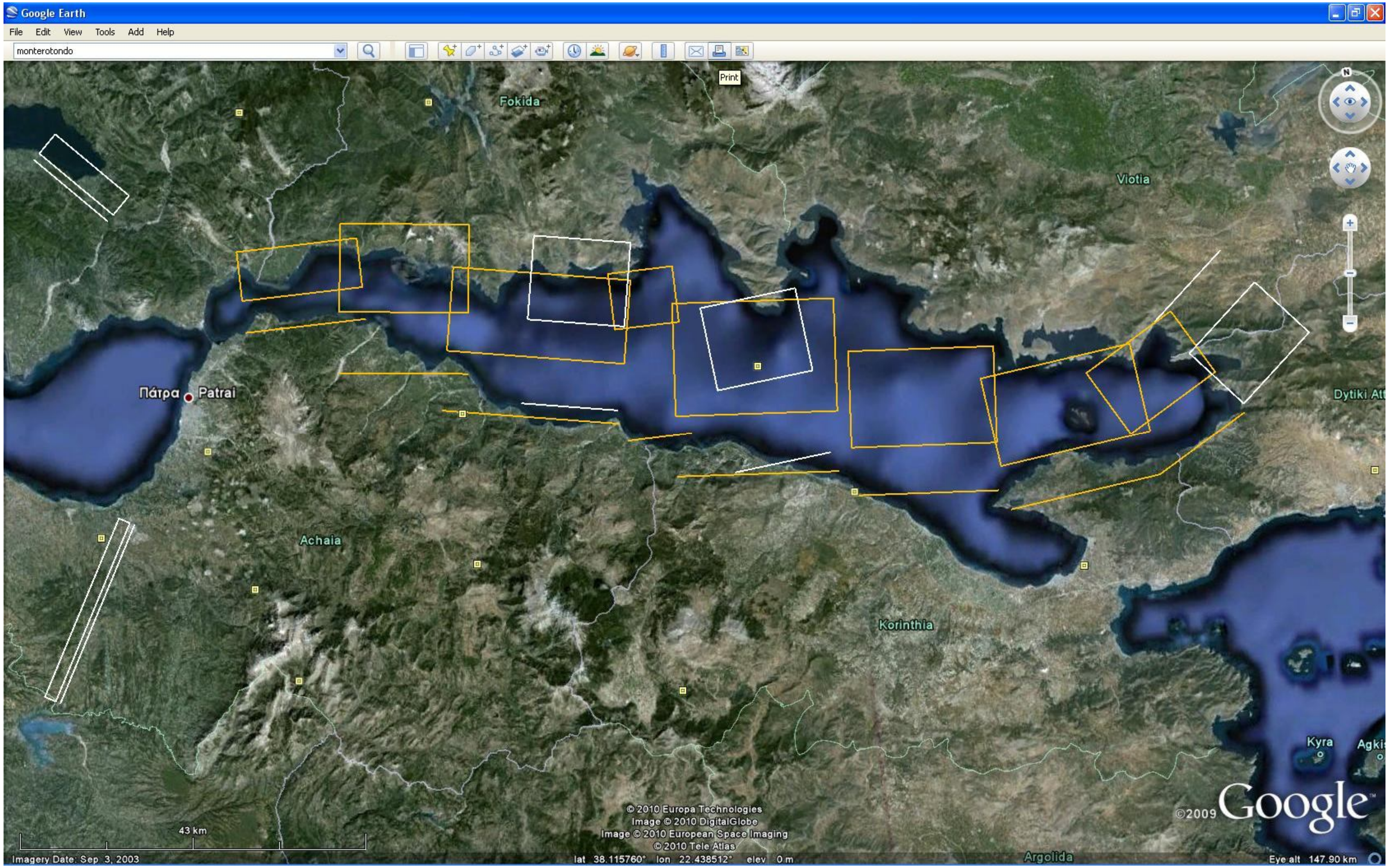
Conditional probability (BPT distribution)



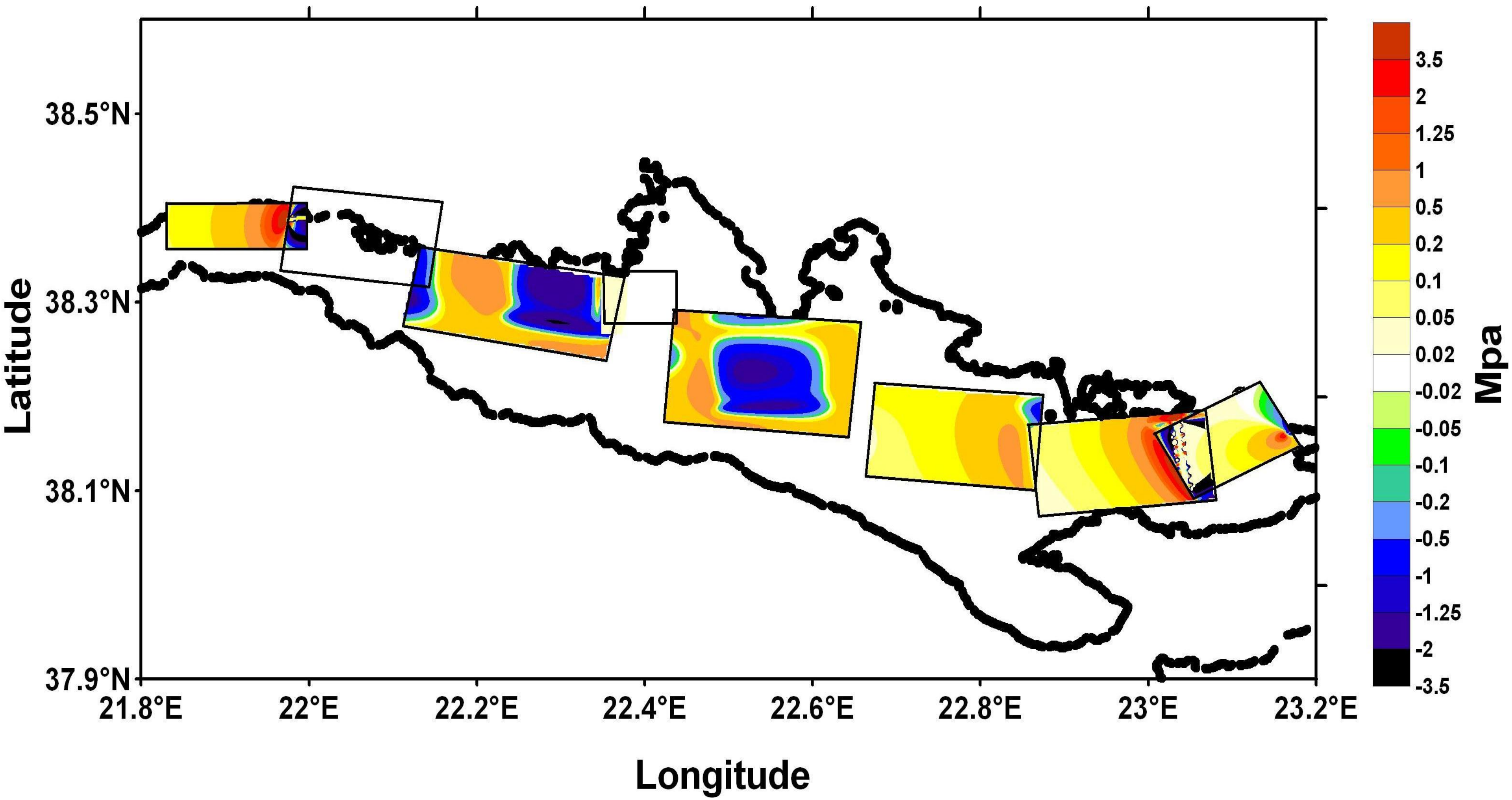
Conditional probability (Weibull distribution)



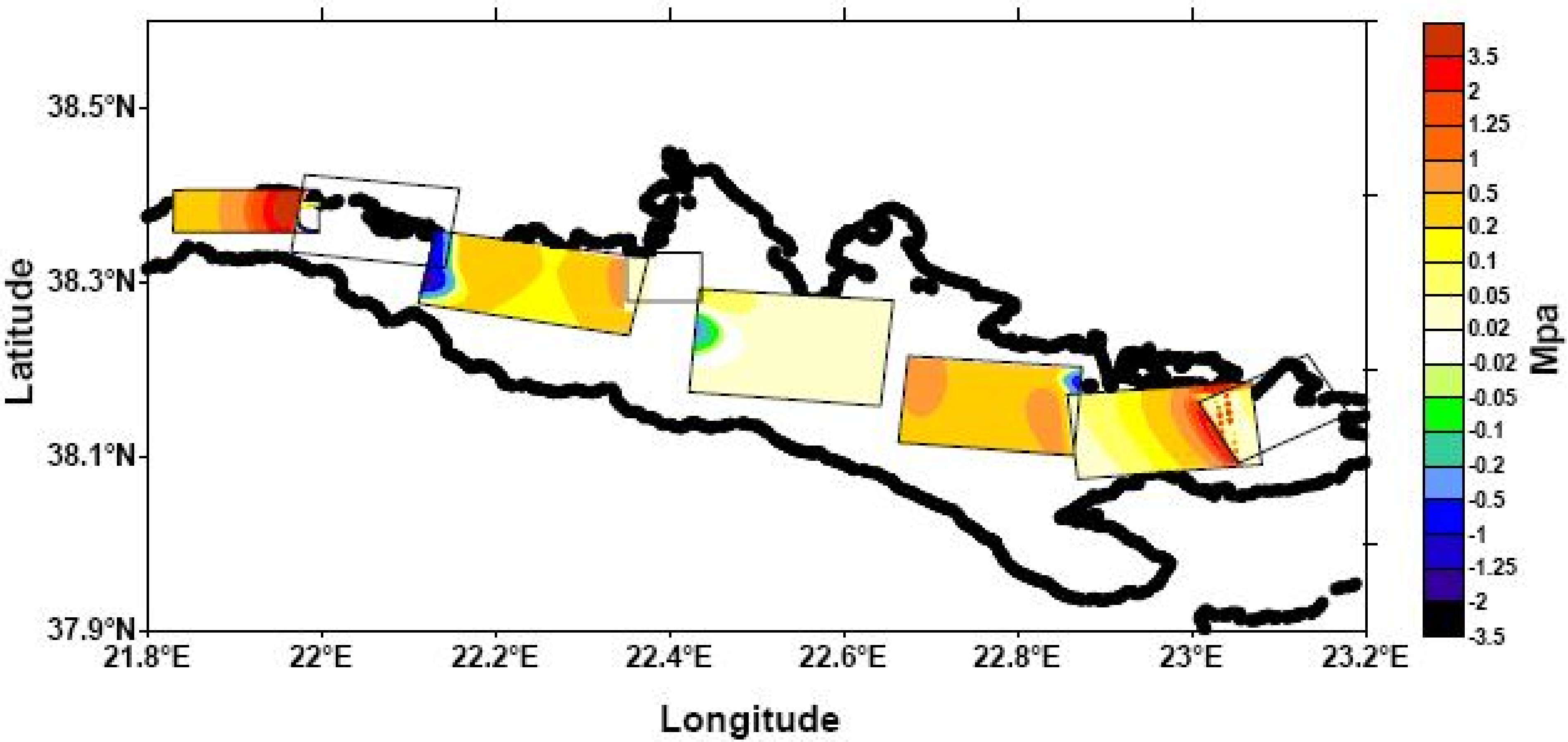
Source modeling in the Corynth Gulf



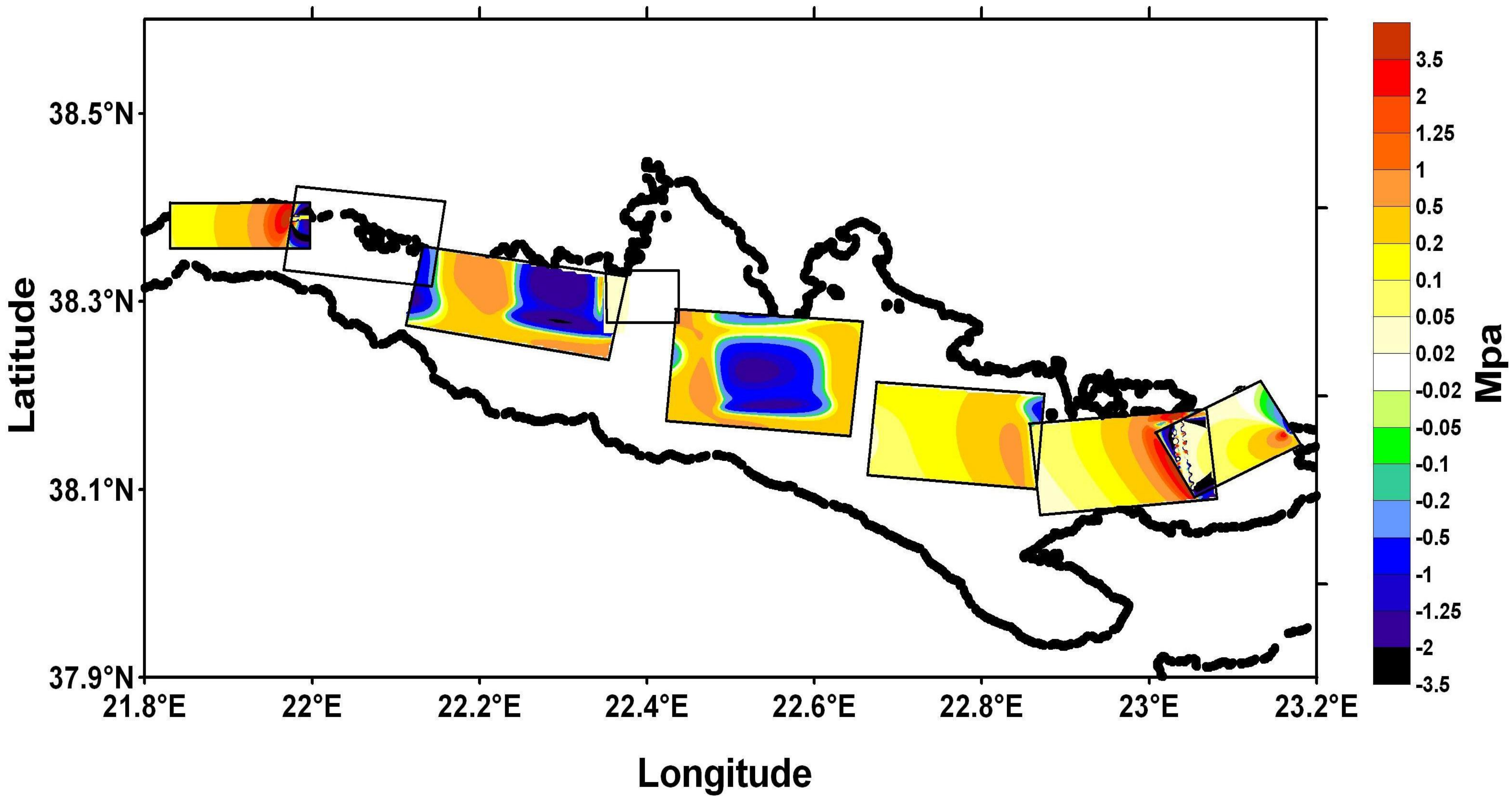
Coulomb stress change estimated at the end of the test (2010)



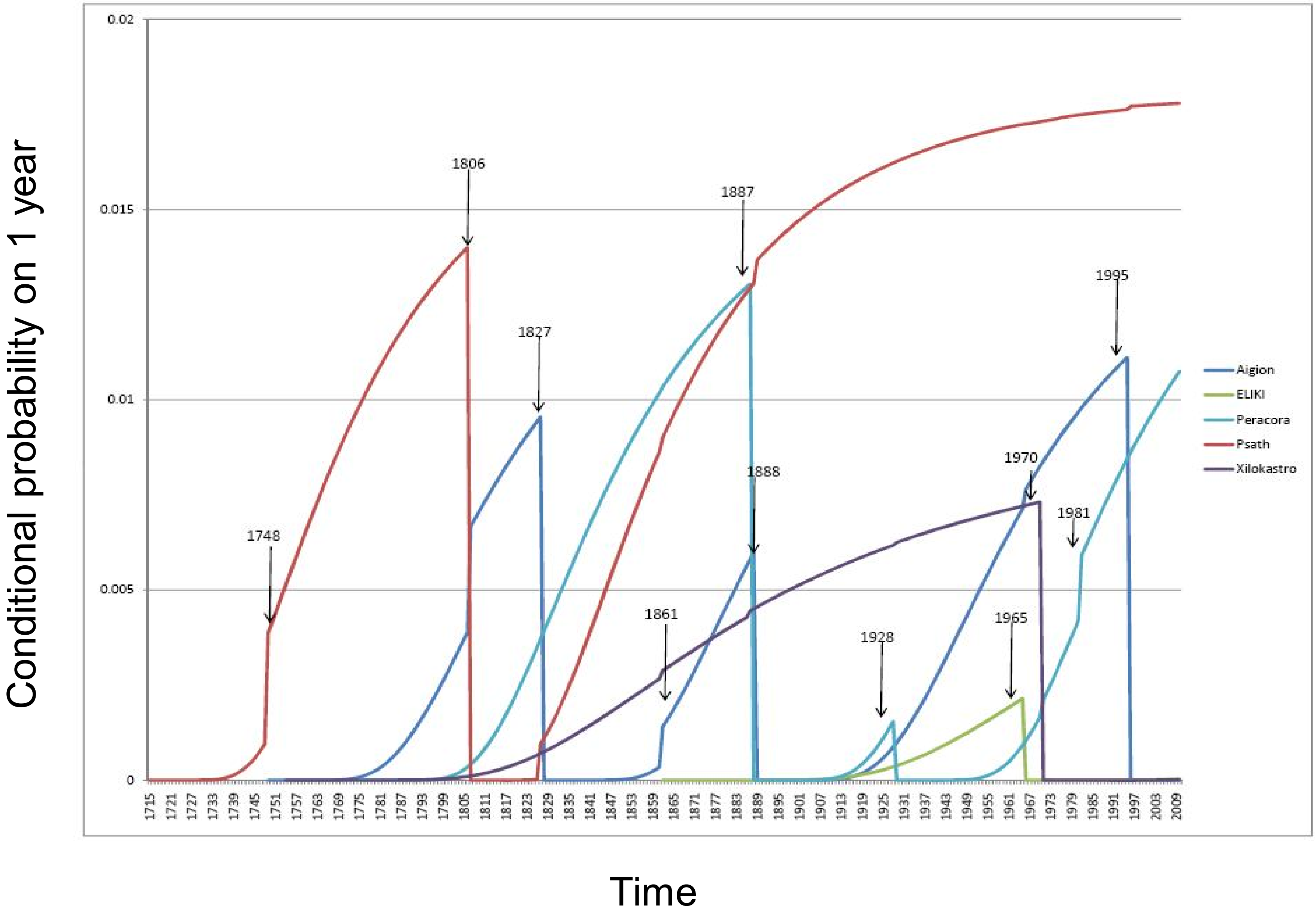
Coulomb stress change estimated at the end of the test (2010)



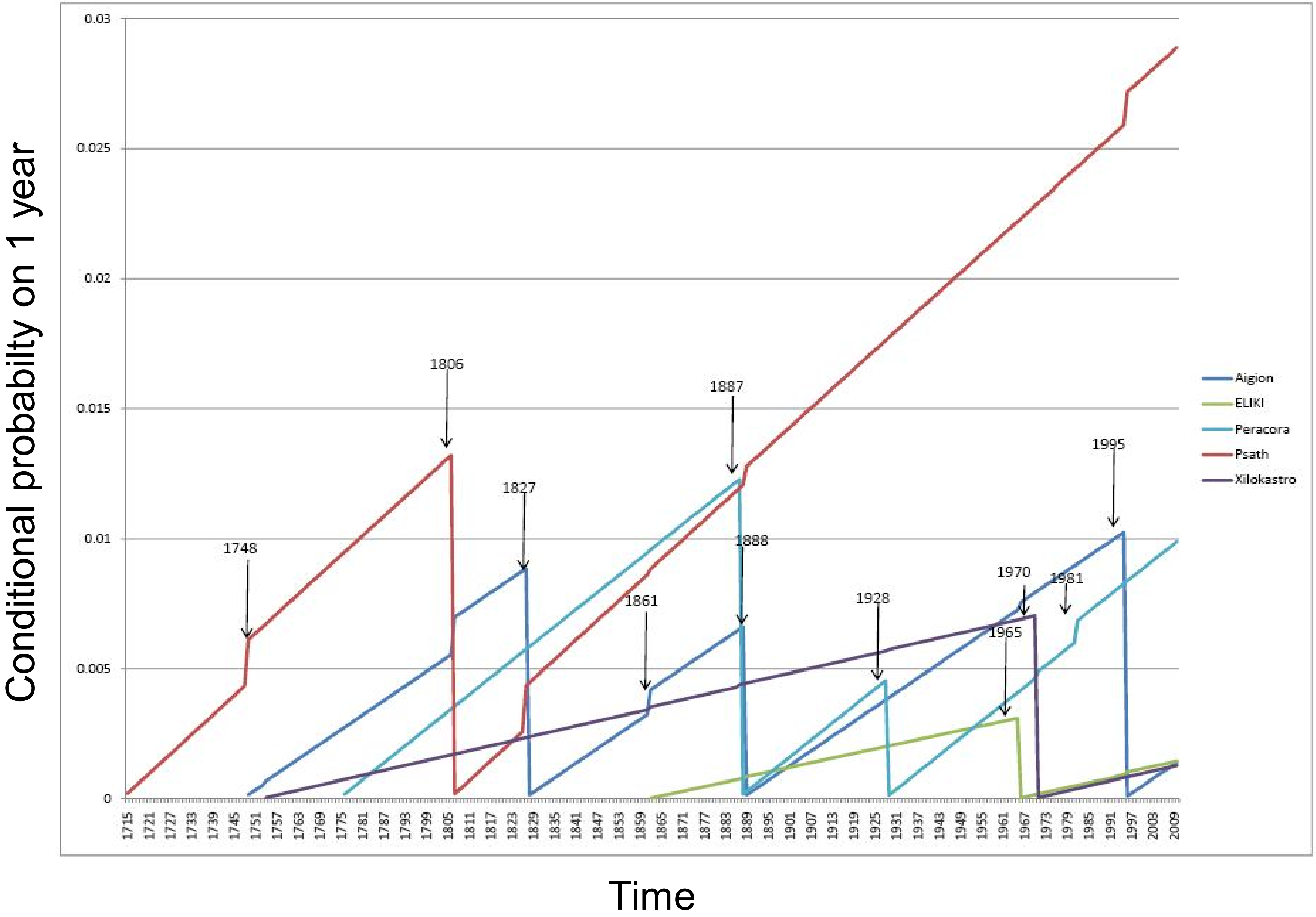
Coulomb stress change estimated at the end of the test (2010)



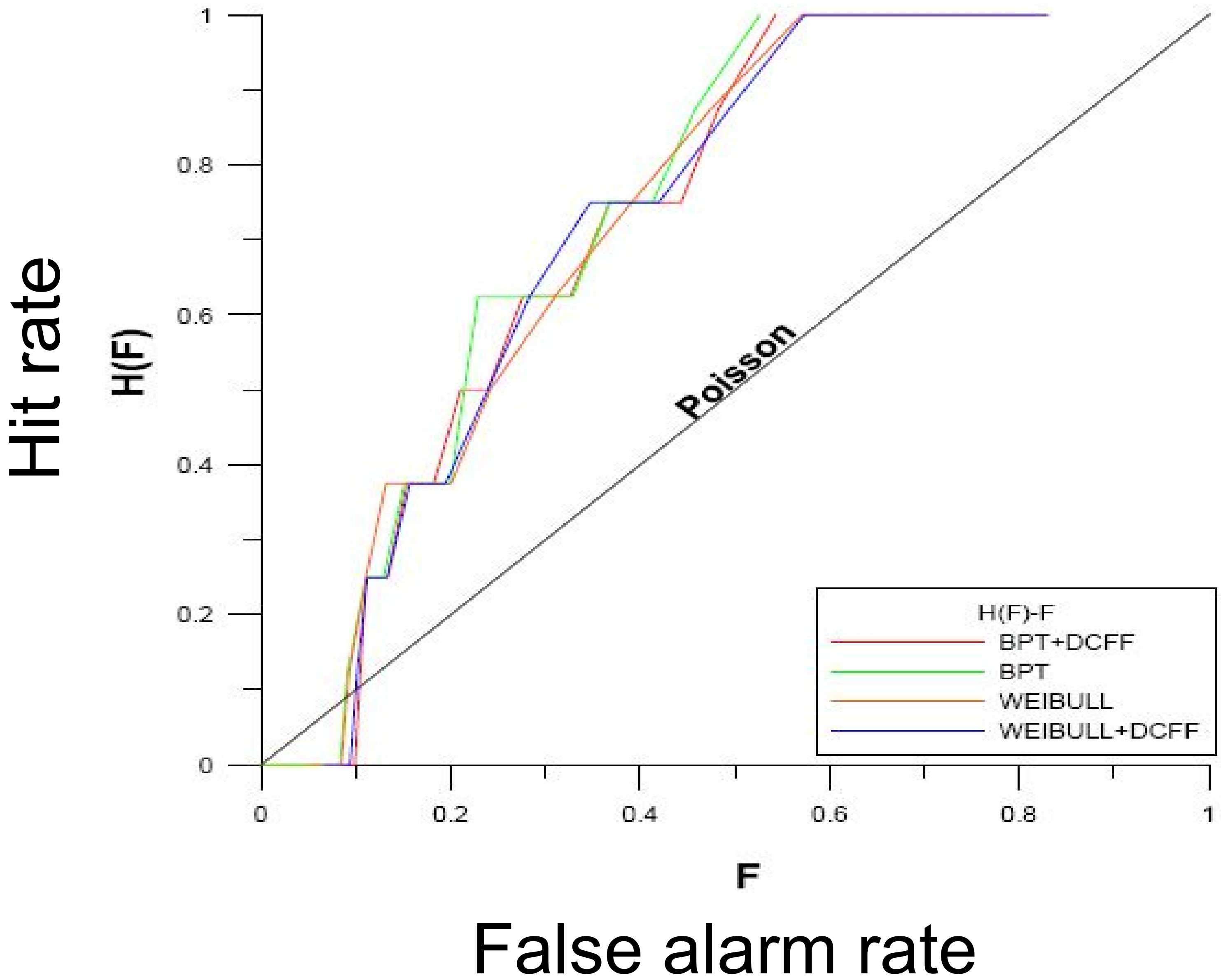
Conditional probability (BPT + DCFF)



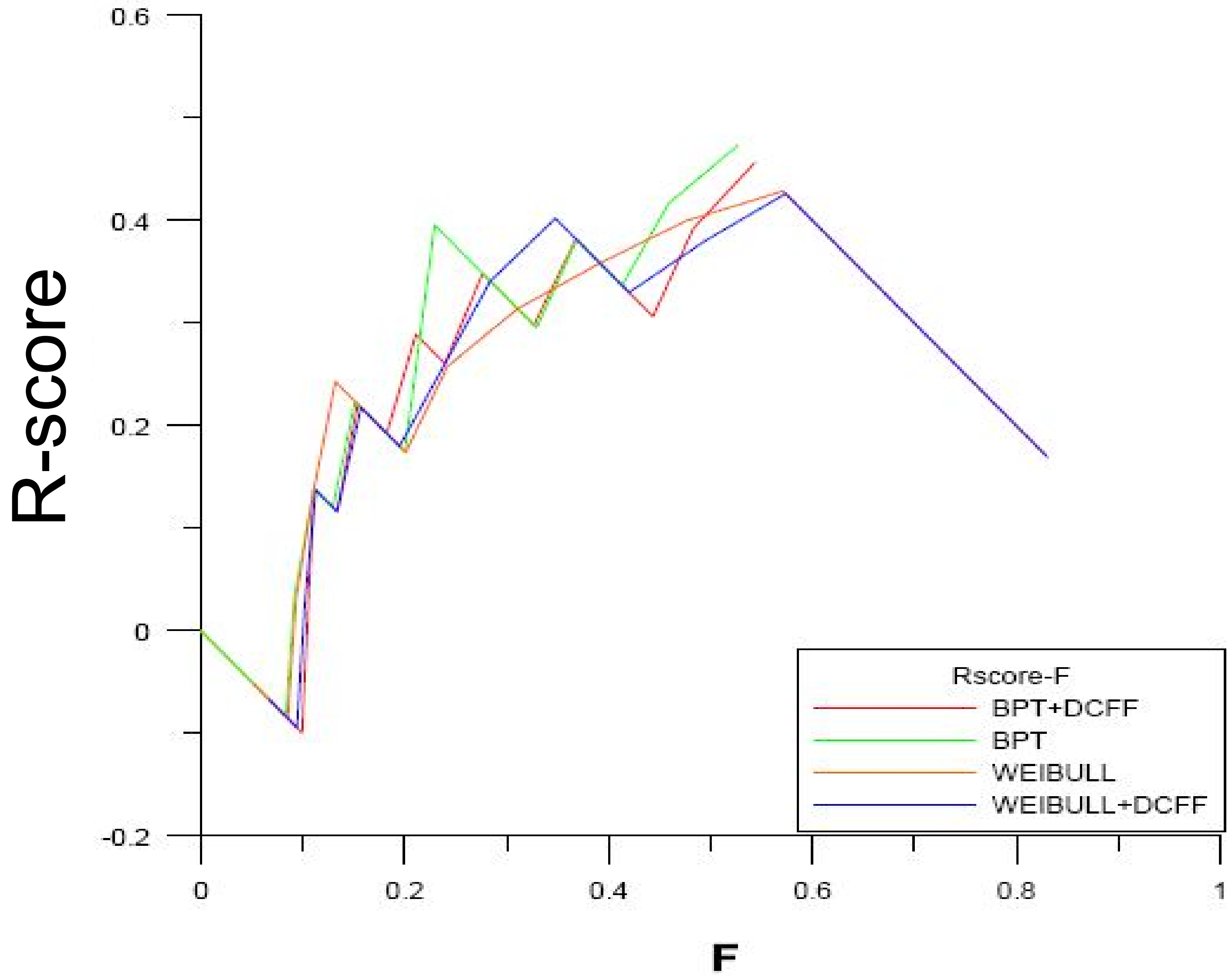
Conditional probability (Weibull + DCFF)



ROC Diagram

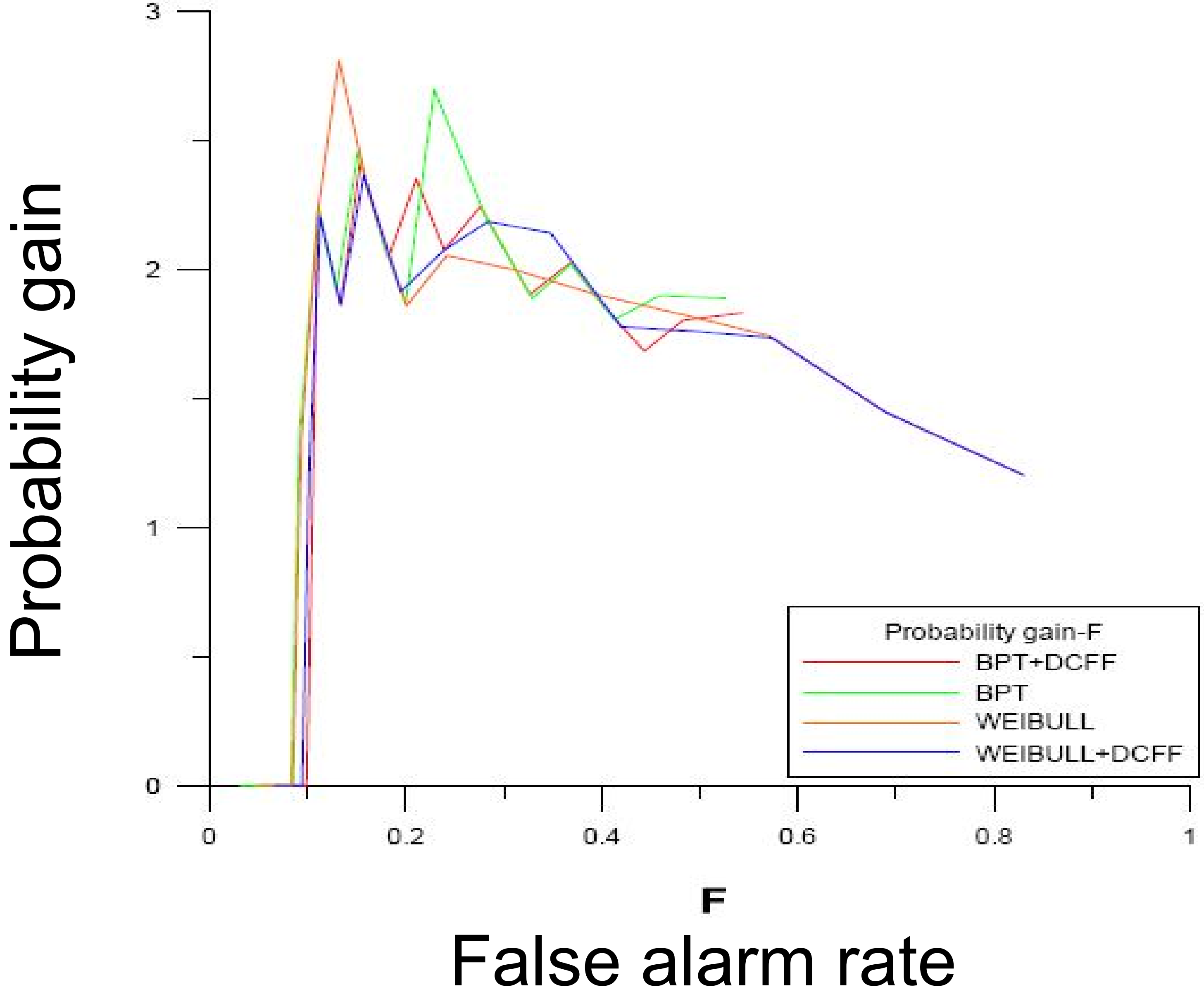

Hit rate
H(F)
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
F
Poisson
H(F)-F
BPT+DCFF
BPT
WEIBULL
WEIBULL+DCFF
False alarm rate

R-score vs. false alarm rate

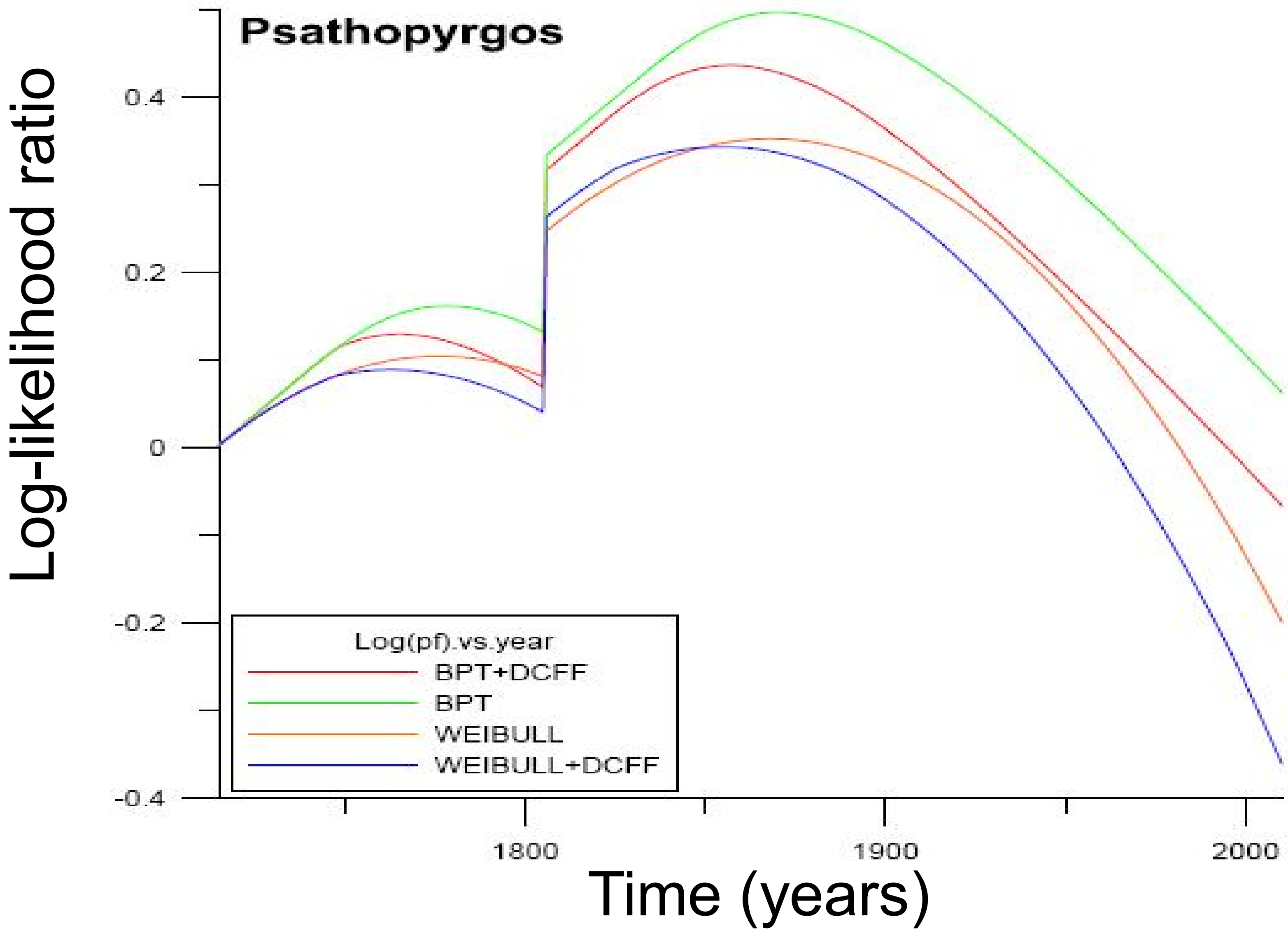


False alarm rate

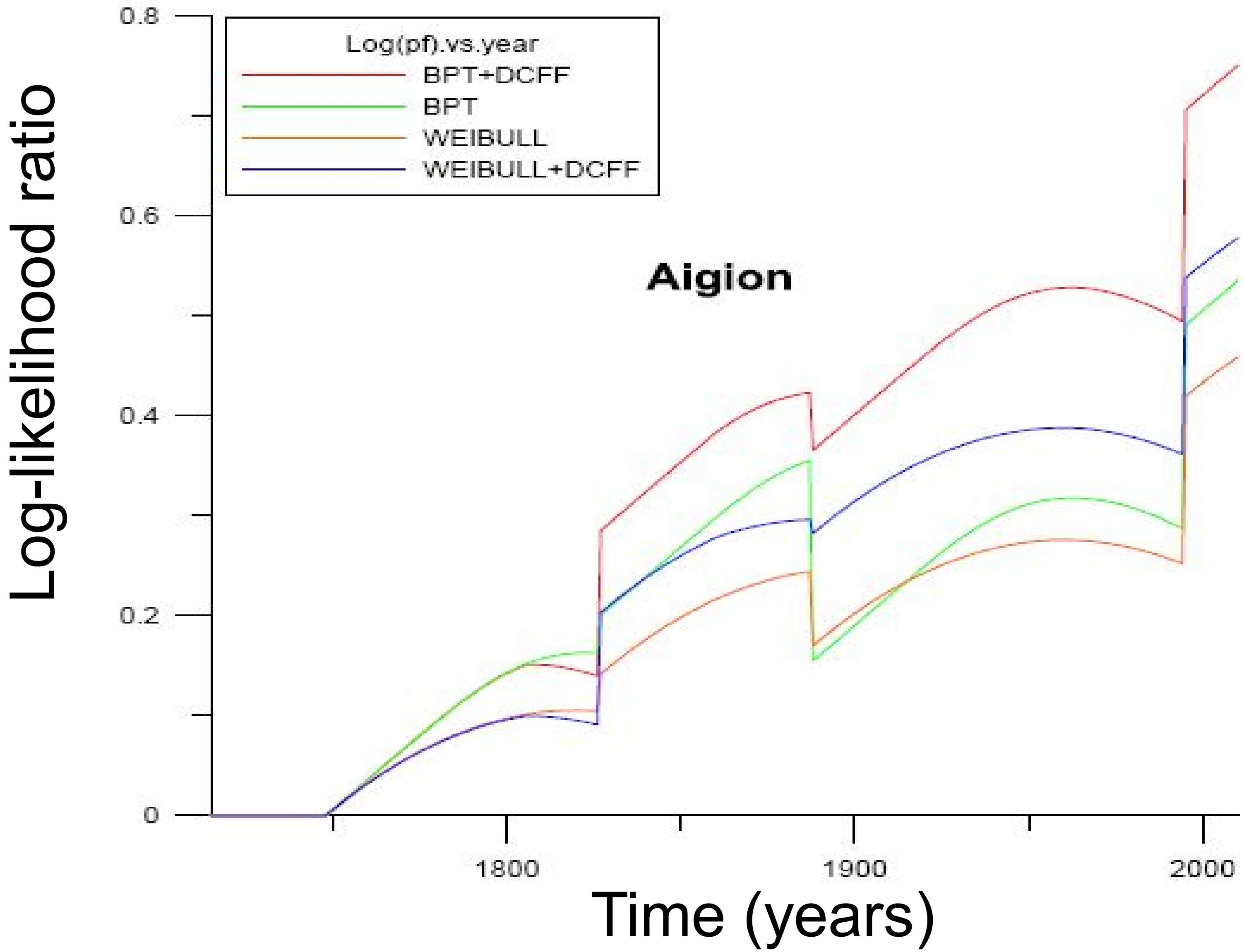
Probability gain vs. false alarm rate



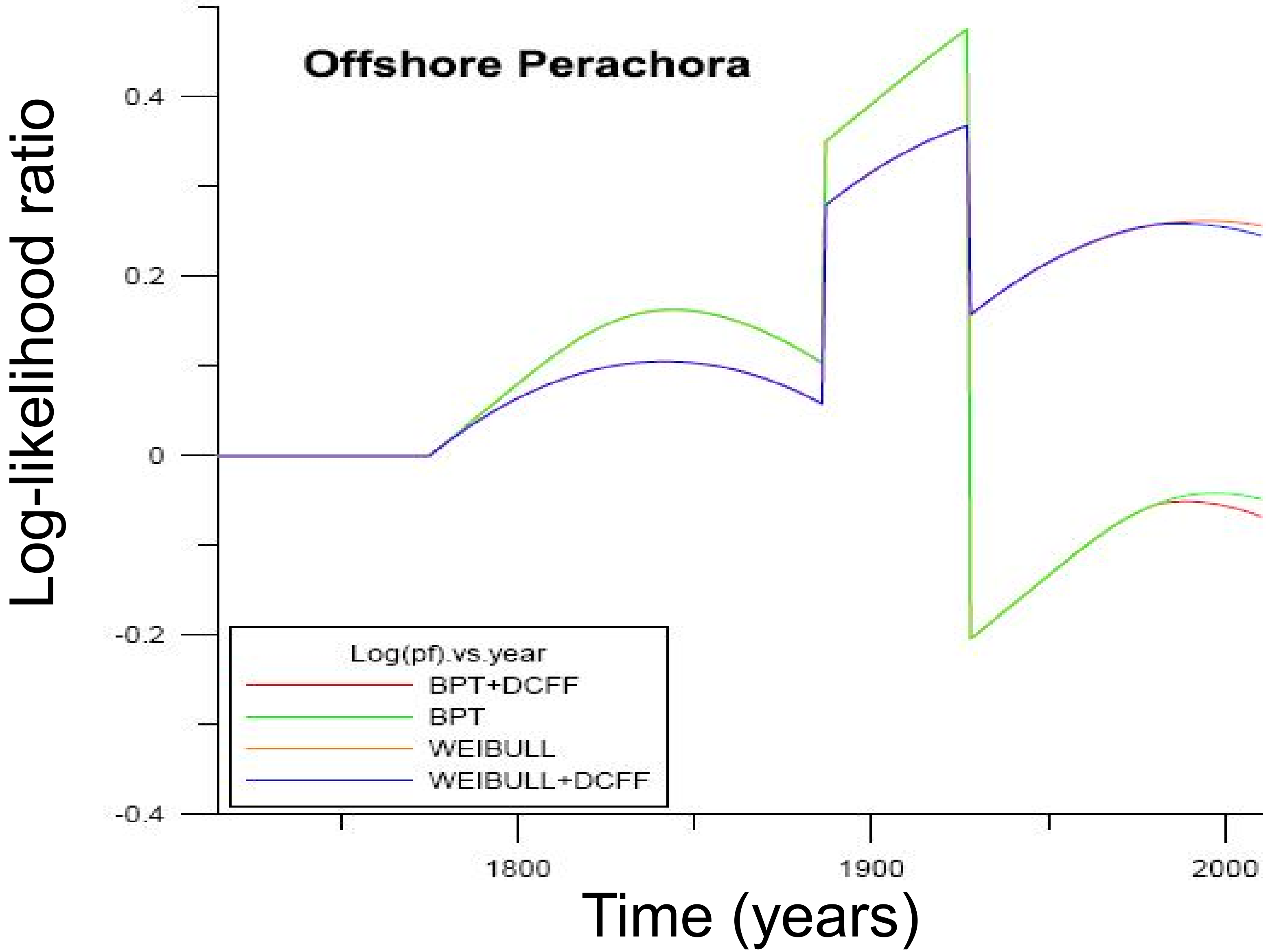
Log-likelihood ratio assuming the Poisson hypothesis as reference model (Psathopyrgos segment)



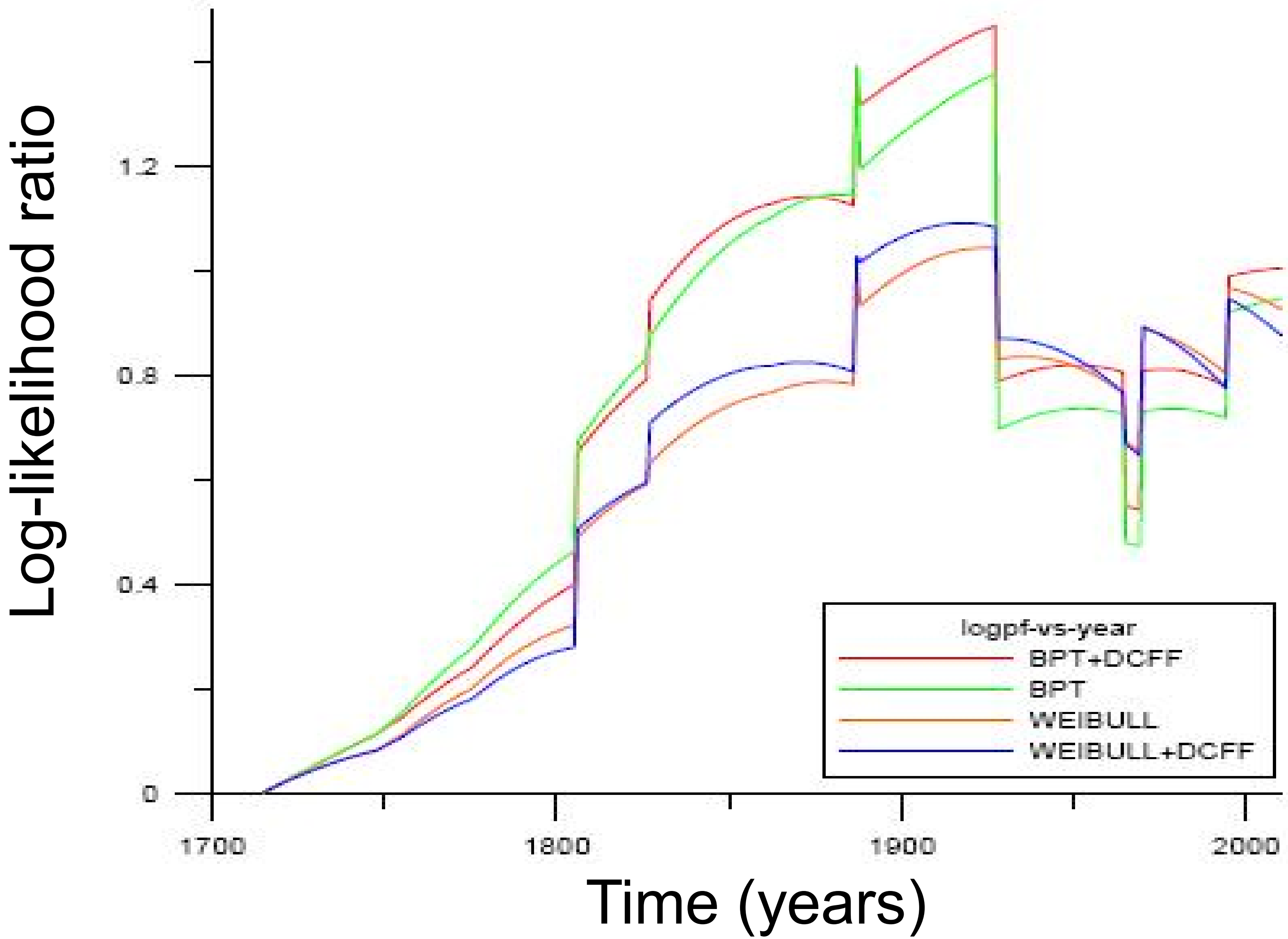
Log-likelihood ratio assuming the Poisson hypothesis as reference model (Aigion segment)



Log-likelihood ratio assuming the Poisson hypothesis as reference model (Perachora segment)



Log-likelihood ratio assuming the Poisson hypothesis as reference model (Corinth Gulf fault system)



Comparison between different hypotheses (final log-likelihood ratio)

$$\text{Log } R = \text{Log}(L) - \text{Log}(L_0)$$

1) L=BPT, L_0=Poisson	Log R=0.95
2) L=BPT+DCFF, L_0=Poisson	Log R=1.01
3) L=BPT+DCFF, L_0=BPT	Log R=0.058
4) L=Weibull, L_0=Poisson	Log R=0.93
5) L=Weibull+DCFF, L_0=Poisson	Log R=0.88
6) L=Weibull+DCFF, L_0=Weibull	Log R=-0.050

CONCLUSIONS

The characteristic earthquake hypothesis modeled by the BPT or the Weibull distributions has been tested on the system of 8 segments in the southern coast of the Corinth Gulf (Greece).

The renewal (time-dependent) hypothesis performs slightly better than the time-independent Poisson hypothesis.

The BPT and the Weibull distributions achieve very similar results.

The inclusion in the model of the clock change due to co-seismic static stress interaction among different segments doesn’t seem to improve the results.