Predictability experiments of earthquakes in Italy

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3. USC/SCEC
4. INGV

Credits

Retrospective results from Werner *et al*., in review

Real-time experiment results from Marzocchi & Lombardi 2009 GRL

Risk assessment perspective from van Stiphout *et al*. 2010 GRL (in press)

Discussed:

Earthquake predictability experiments,

CSEP Italy retrospective analysis,

Real-time earthquake forecasting,

Probabilistic loss estimation

Earthquake predictability experiment

We consider binned space-rate-magnitude forecasts and compare forecasts with each other and with similarly binned observations.

In prospective experiments, forecast values are fixed before making the relevant observations.

In retrospective experiments, forecasts and observations might not be independent.

Forecast format

The geographic region of interest is divided into spatial cells (e.g., 0.1° x 0.1°).

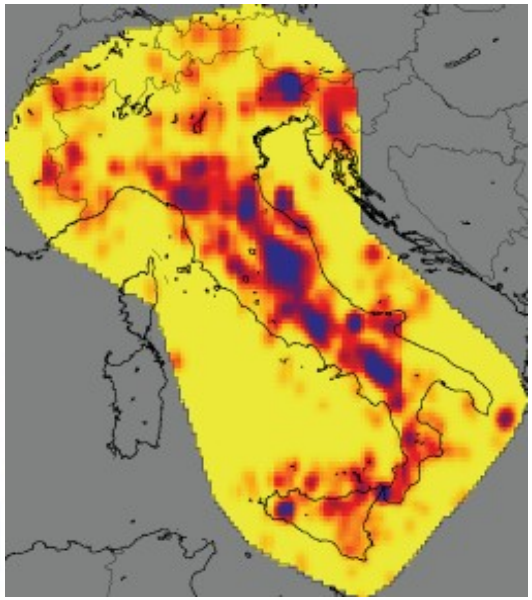
The spatial cells are divided into magnitude bins (e.g., 0.1 units).

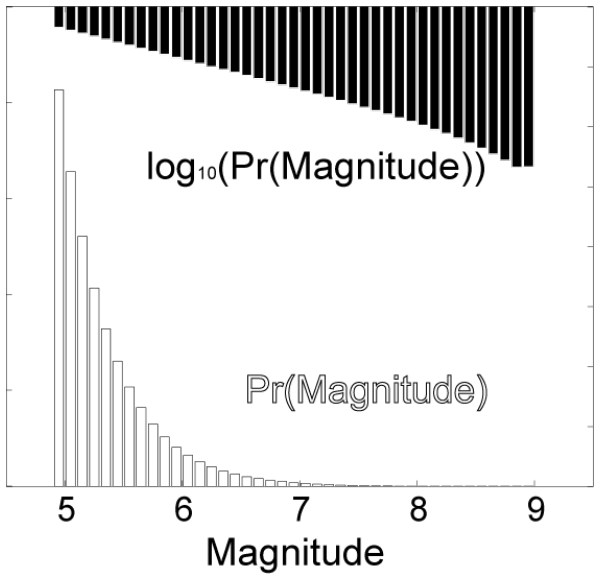
For a fixed time period (e.g., 5 years), a forecast specifies the expected number of earthquakes in each latitude-longitude-magnitude bin.

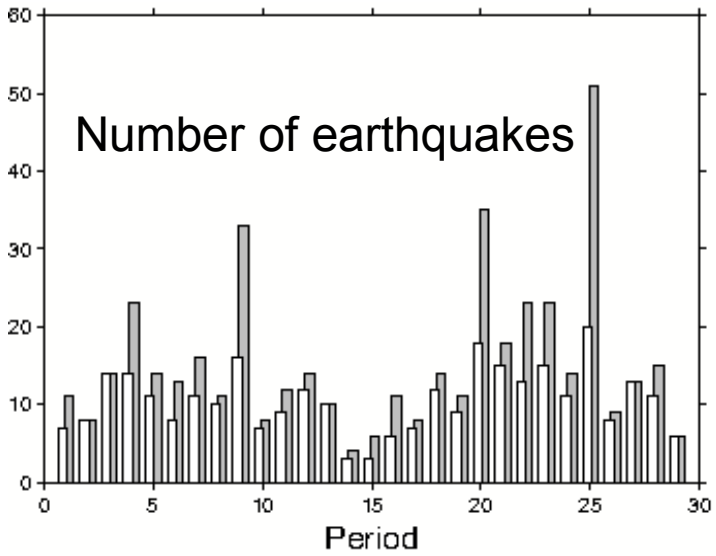
For example, I expect 6.9e-7 earthquakes with magnitude 6.95 to 7.05 in the cell with latitude range 44.9°N to 45°N and longitude range 5.5°E to 5.6°E between 1 August 2009 and 1 August 2014.

Recipe for preparing a forecast

- Estimate spatial distribution of seismicity
- Estimate (or assume) magnitude distribution
- Estimate seismicity rate
- Mix vigorously

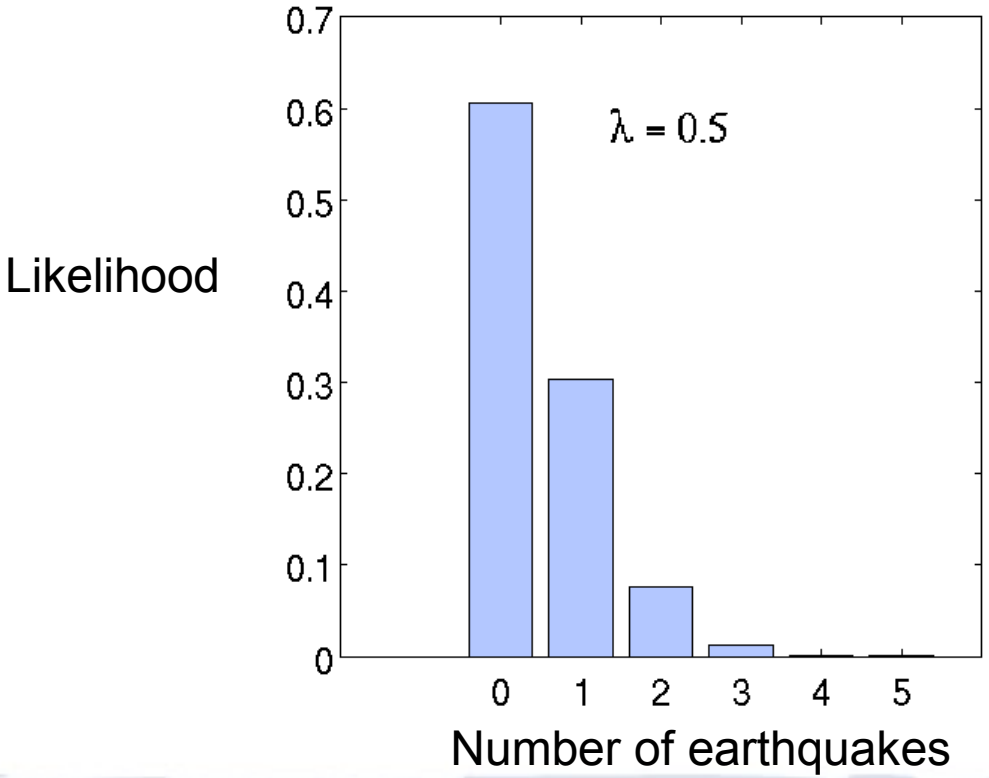






To evaluate

Each forecast is treated as a vector of independent Poisson expectations; its elements are the numbers in each forecast bin.



Tests

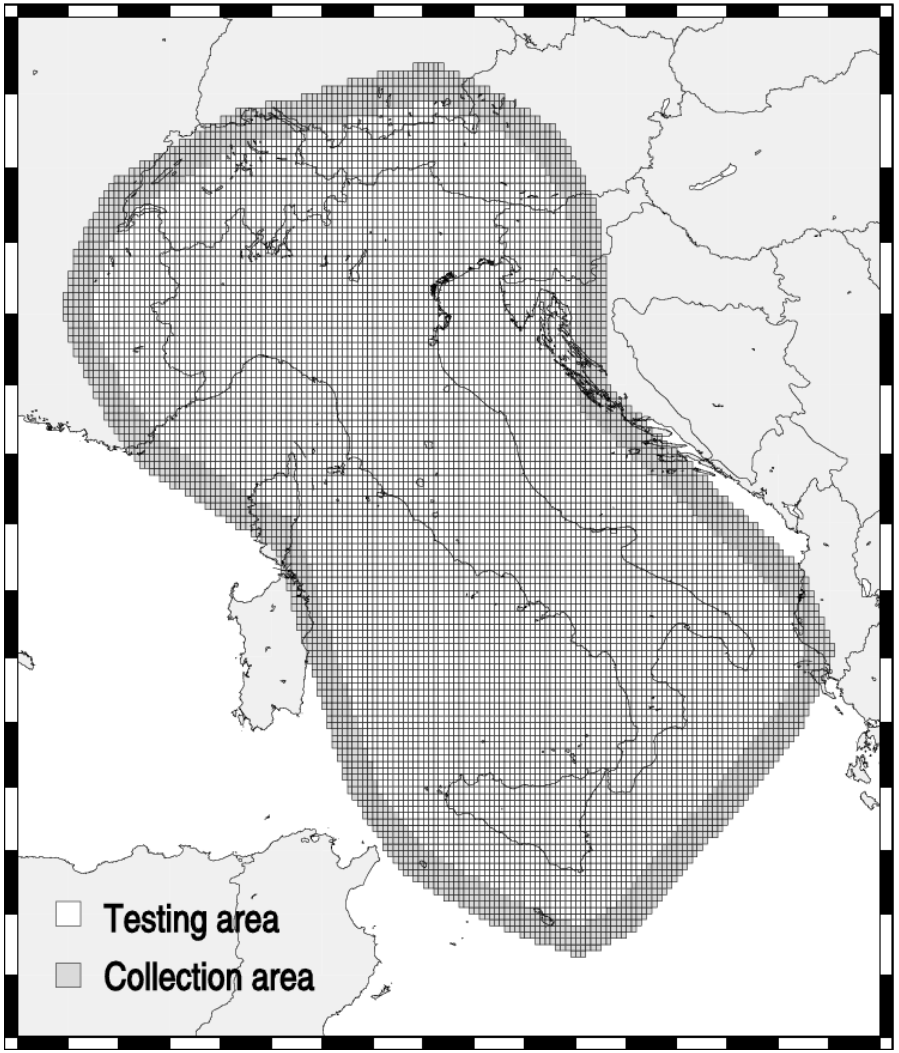
1. N(umber) test compares the number of eqks forecast with the number of eqks observed.
2. L(ikelihood) test compares the forecast space-rate-magnitude distribution with the corresponding observation.
3. S(pace) test compares the forecast spatial distribution with the observed epicenters.
4. M(agnitude) test compares the forecast magnitude distribution with the observed magnitudes.

Result interpretation

We present results in terms of an acceptable range and an observed value. The acceptable range is based on simulations of catalogs that are “consistent with the forecast.”

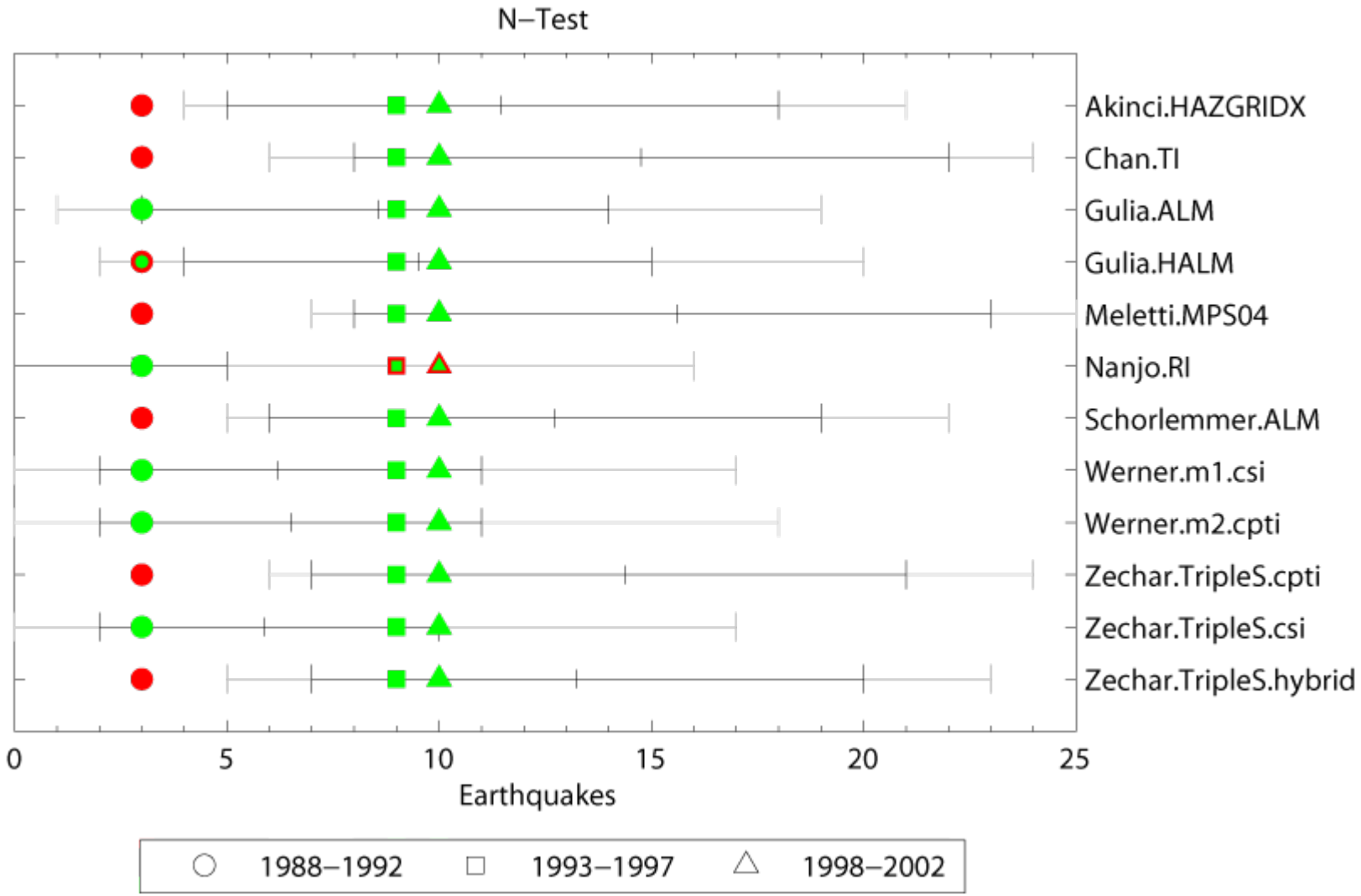
If the observed value is outside the acceptable range, the observation is considered unlikely, given the forecast. Often we use hypothesis testing terms, e.g., “the forecast is *rejected*.”

CSEP Italy experiments

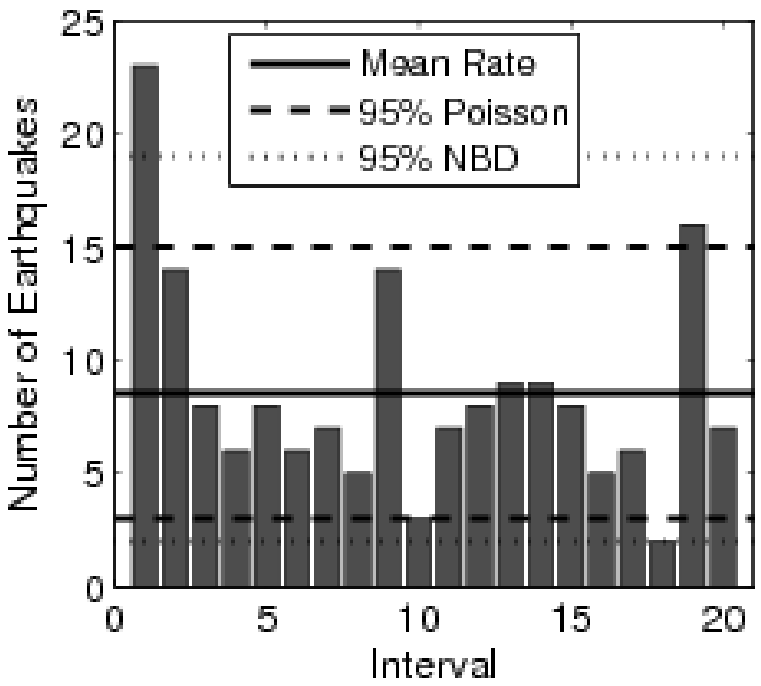


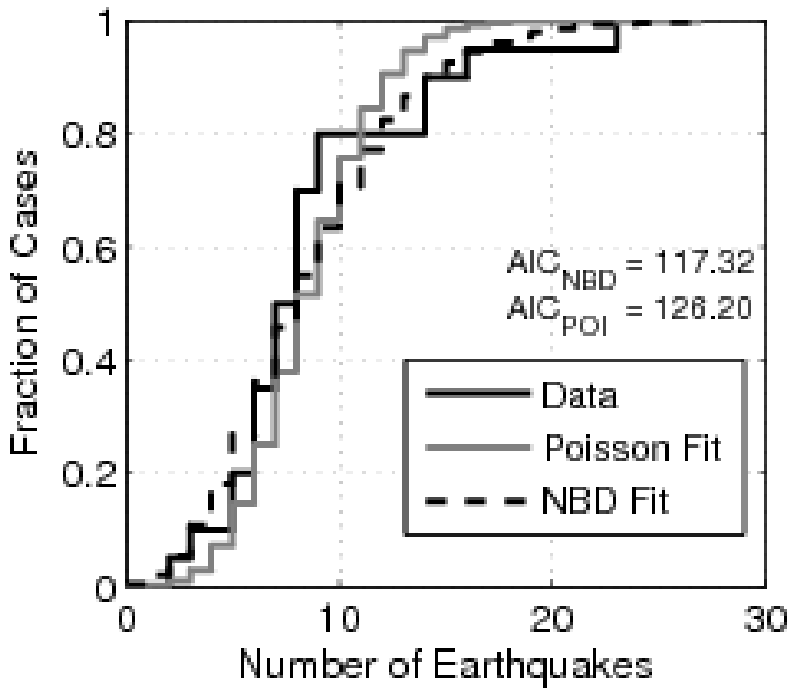
- Forecasts of three-month, five-year, and ten-year duration
- Forecasts based on smoothed seismicity, geological structures, spatial variation of Gutenberg-Richter *b*-value
- Eighteen five-year forecasts being considered

Example result



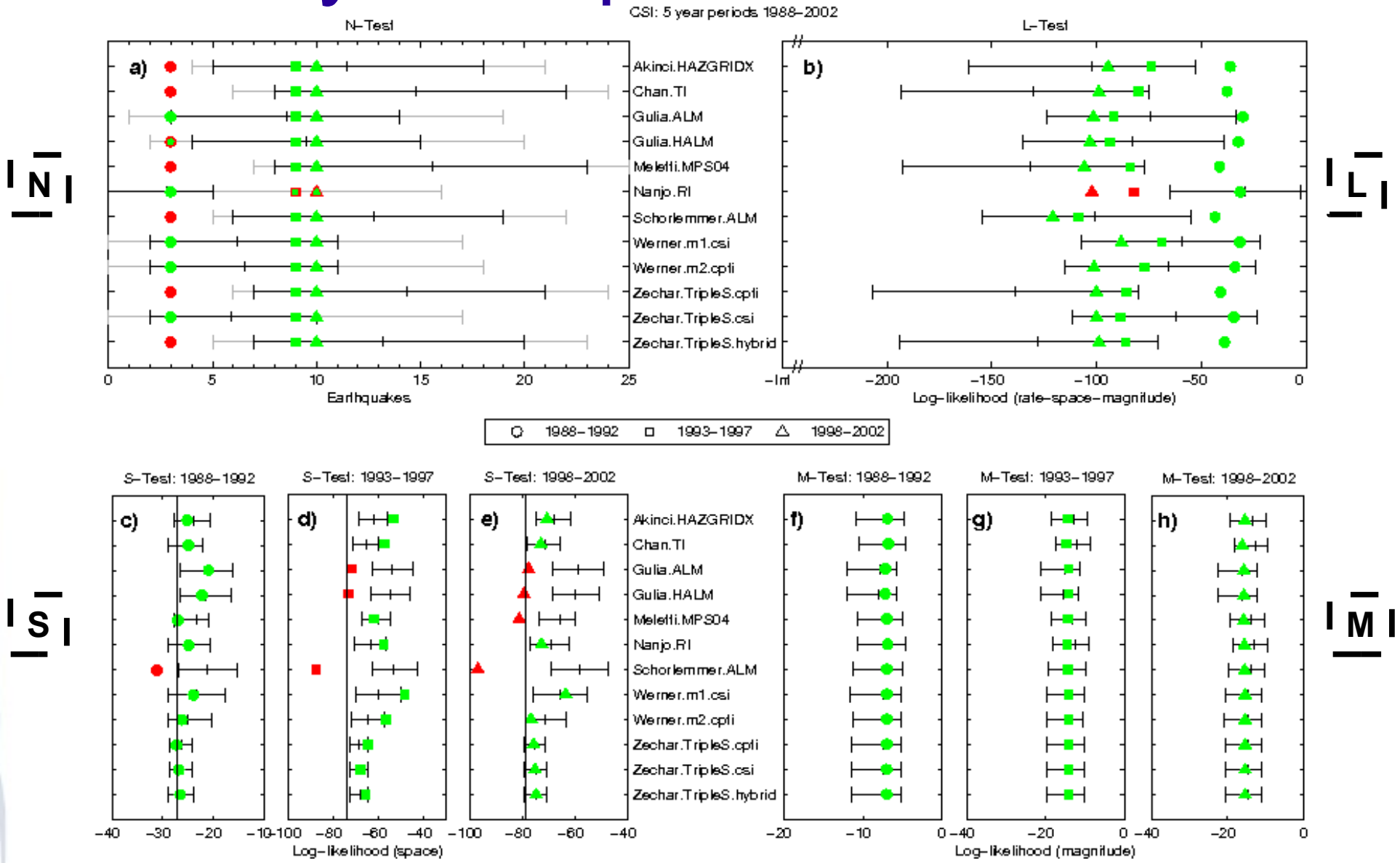
Problem with Poisson assumption



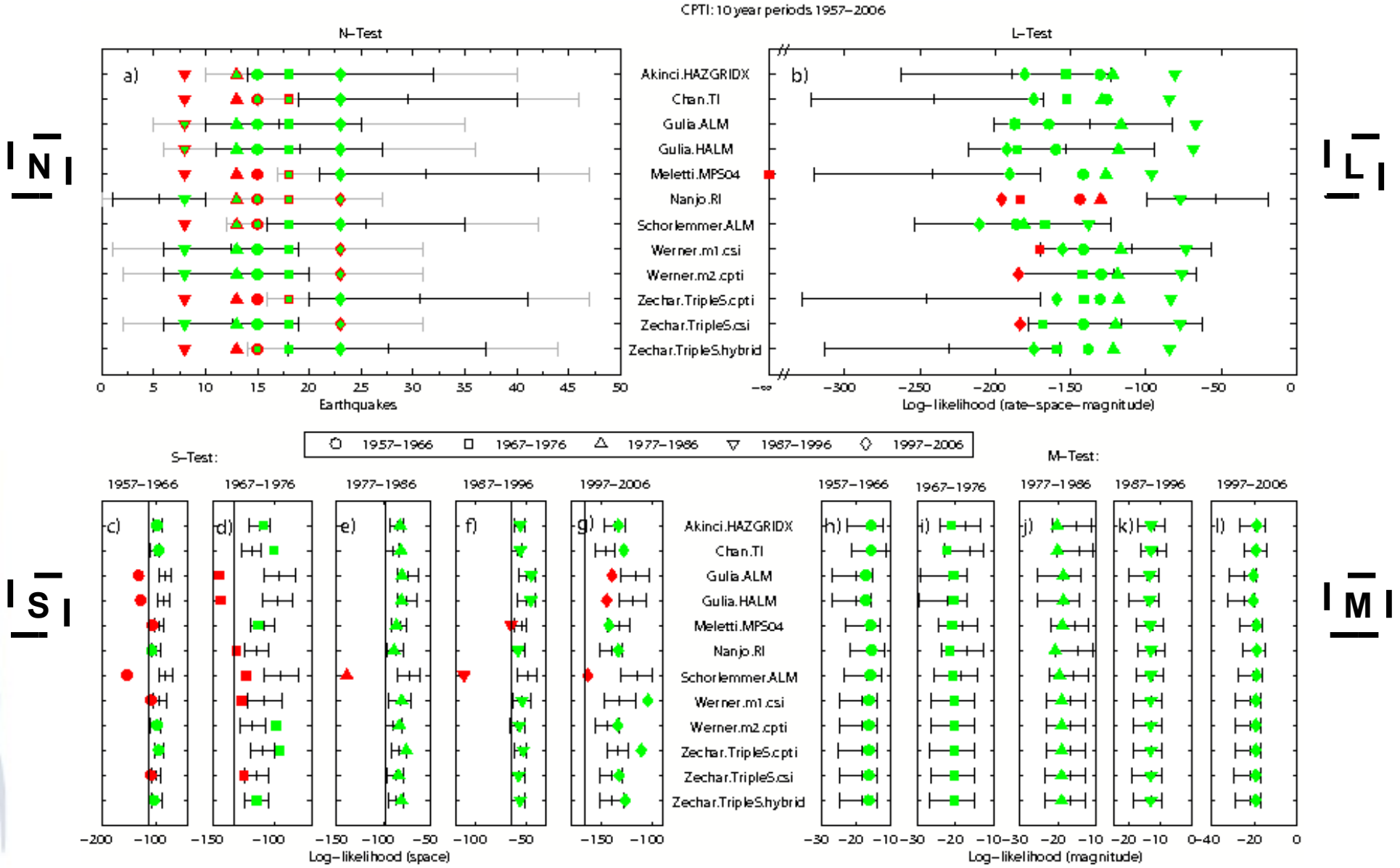


Many researchers have shown that a negative binomial distribution fits the earthquake number distribution better than Poisson.

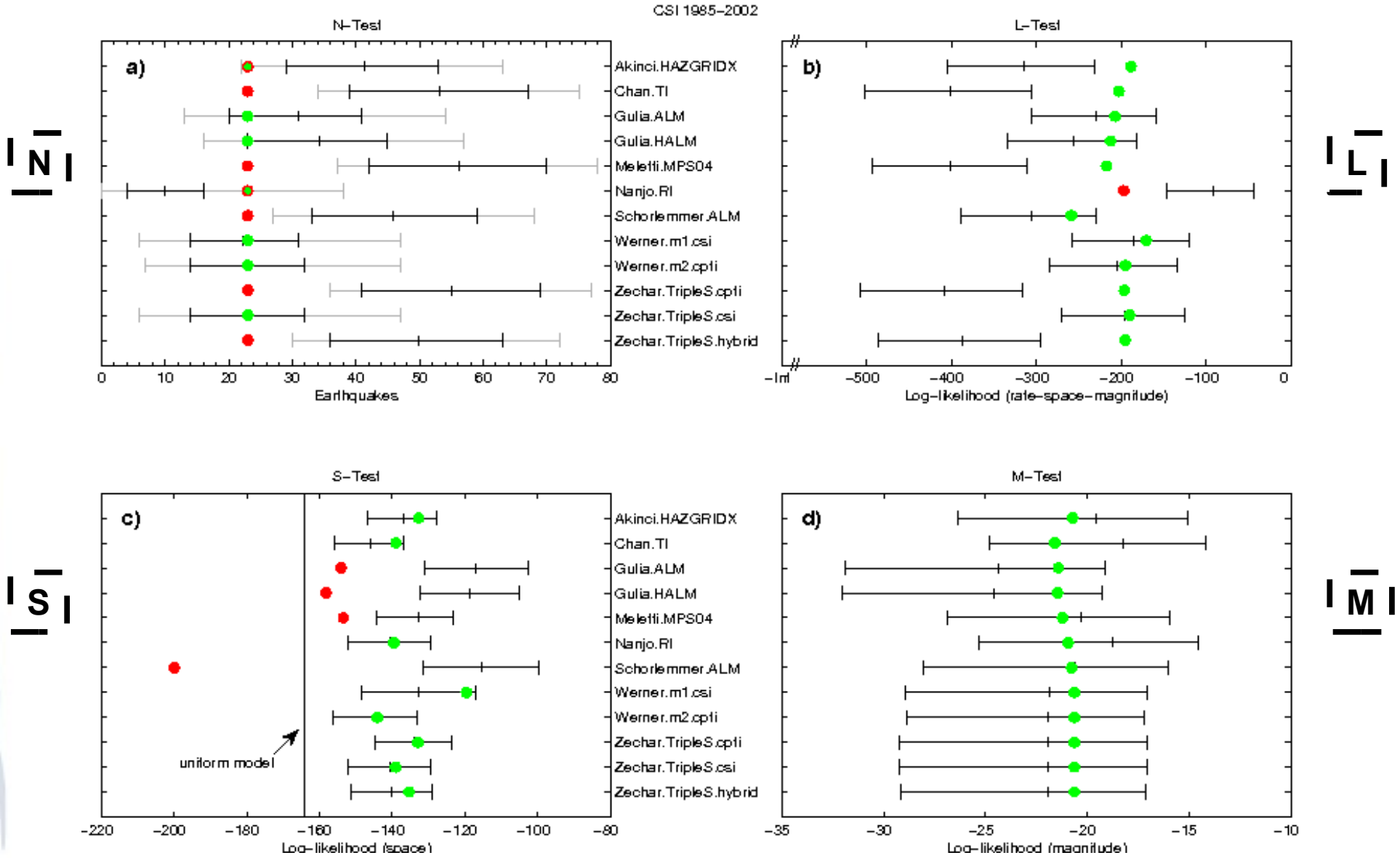
Five-year experiments results



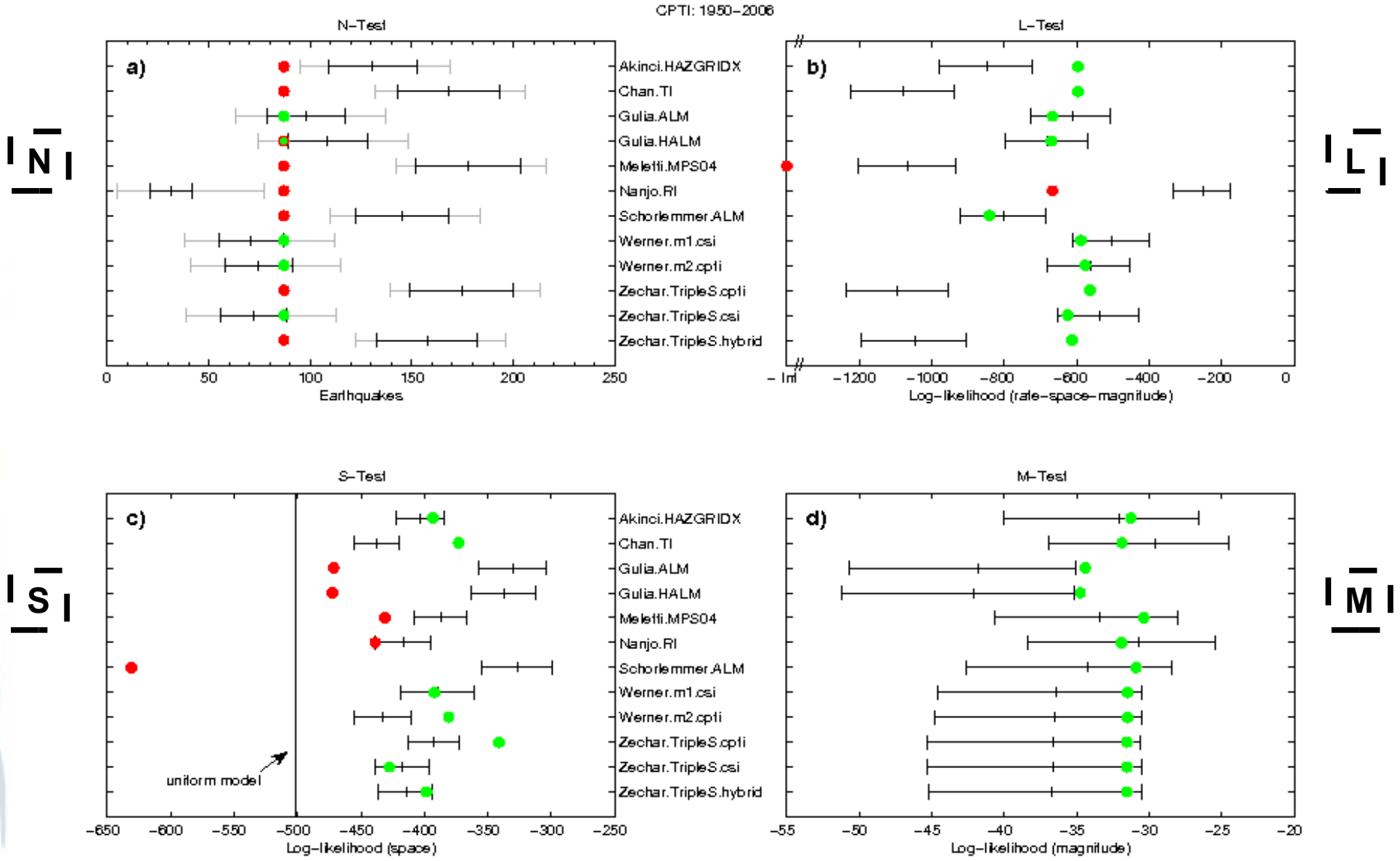
Ten-year experiments results



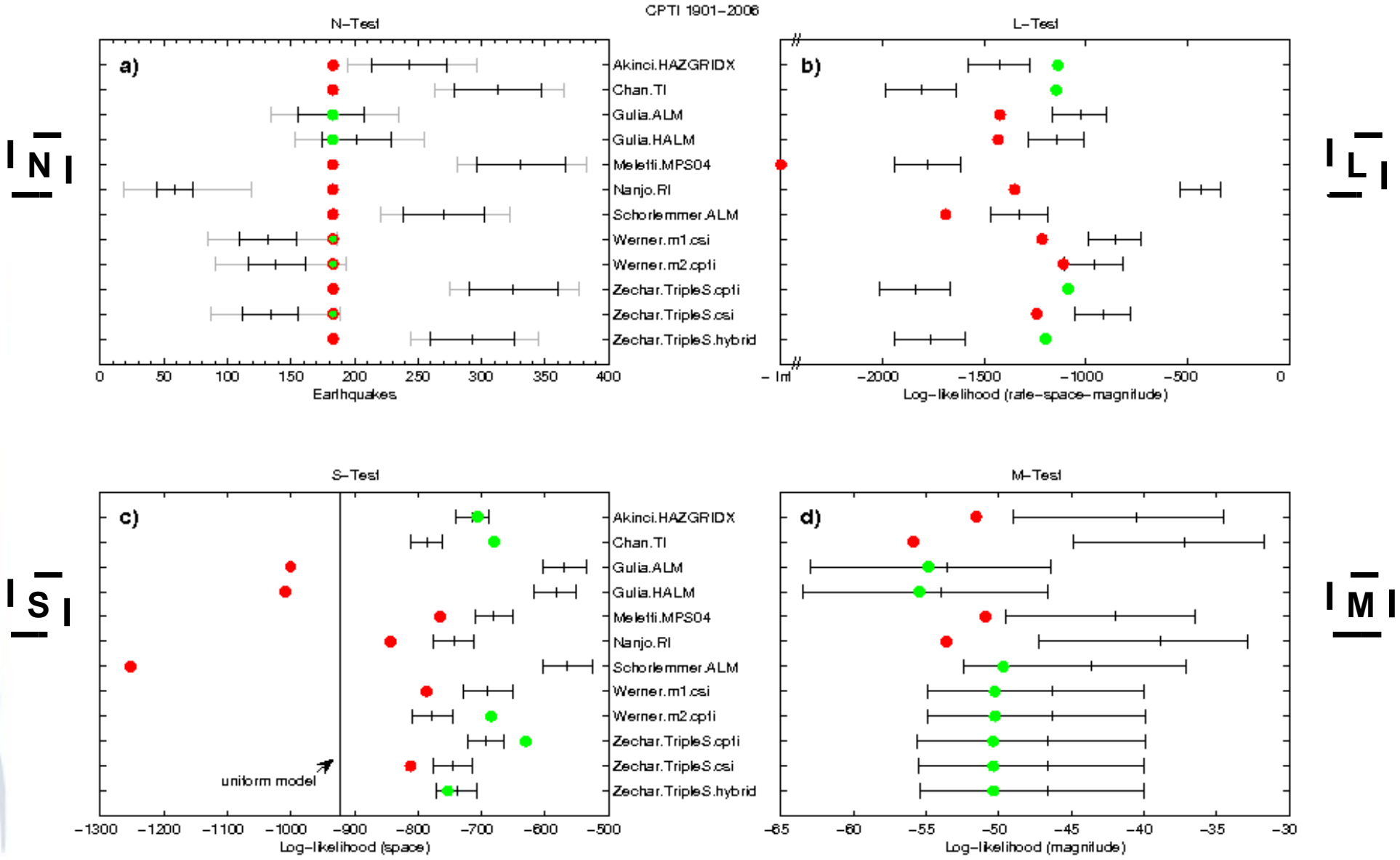
18-year experiment results



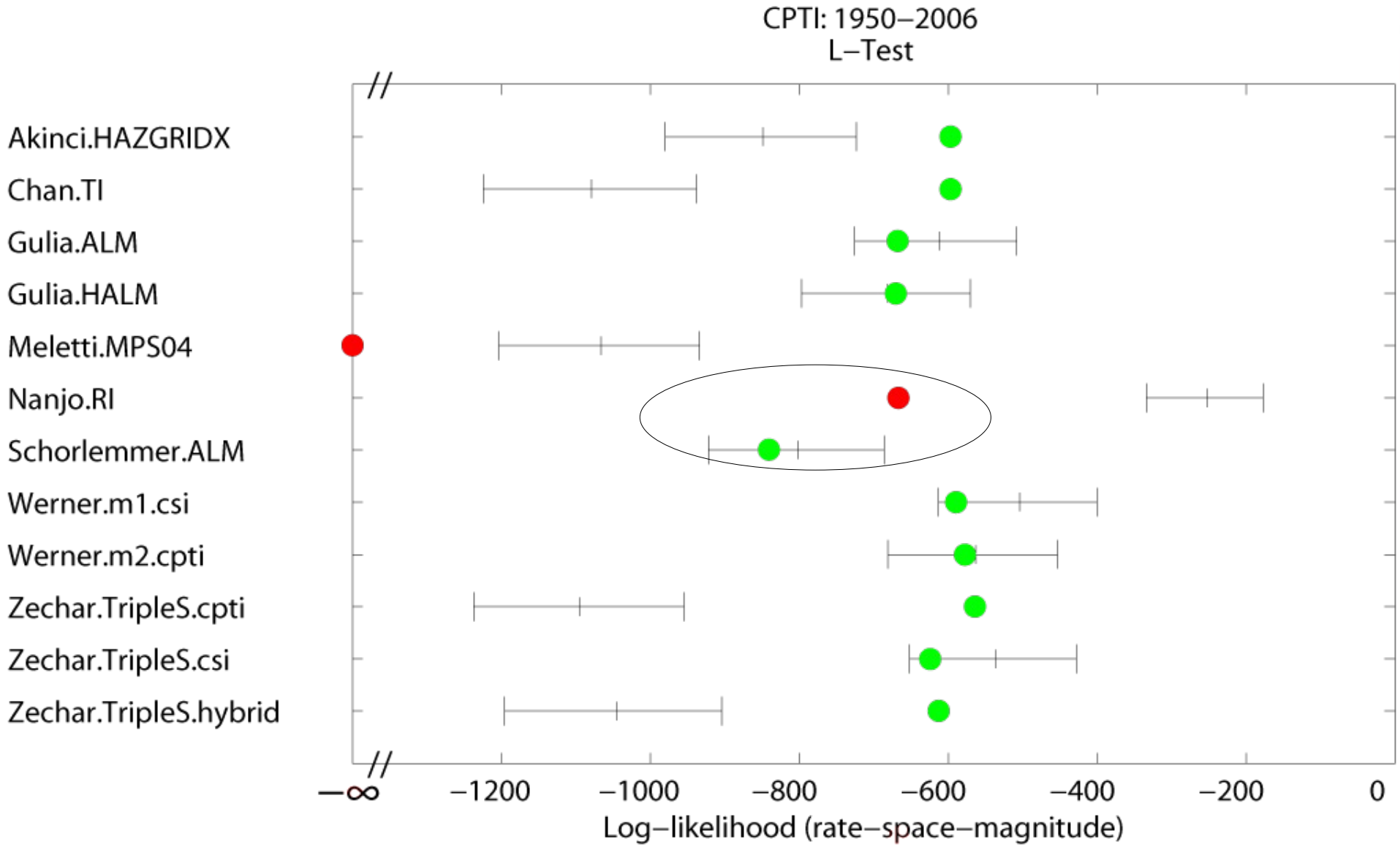
57-year experiment results



106-year experiment results



L-Test subtlety



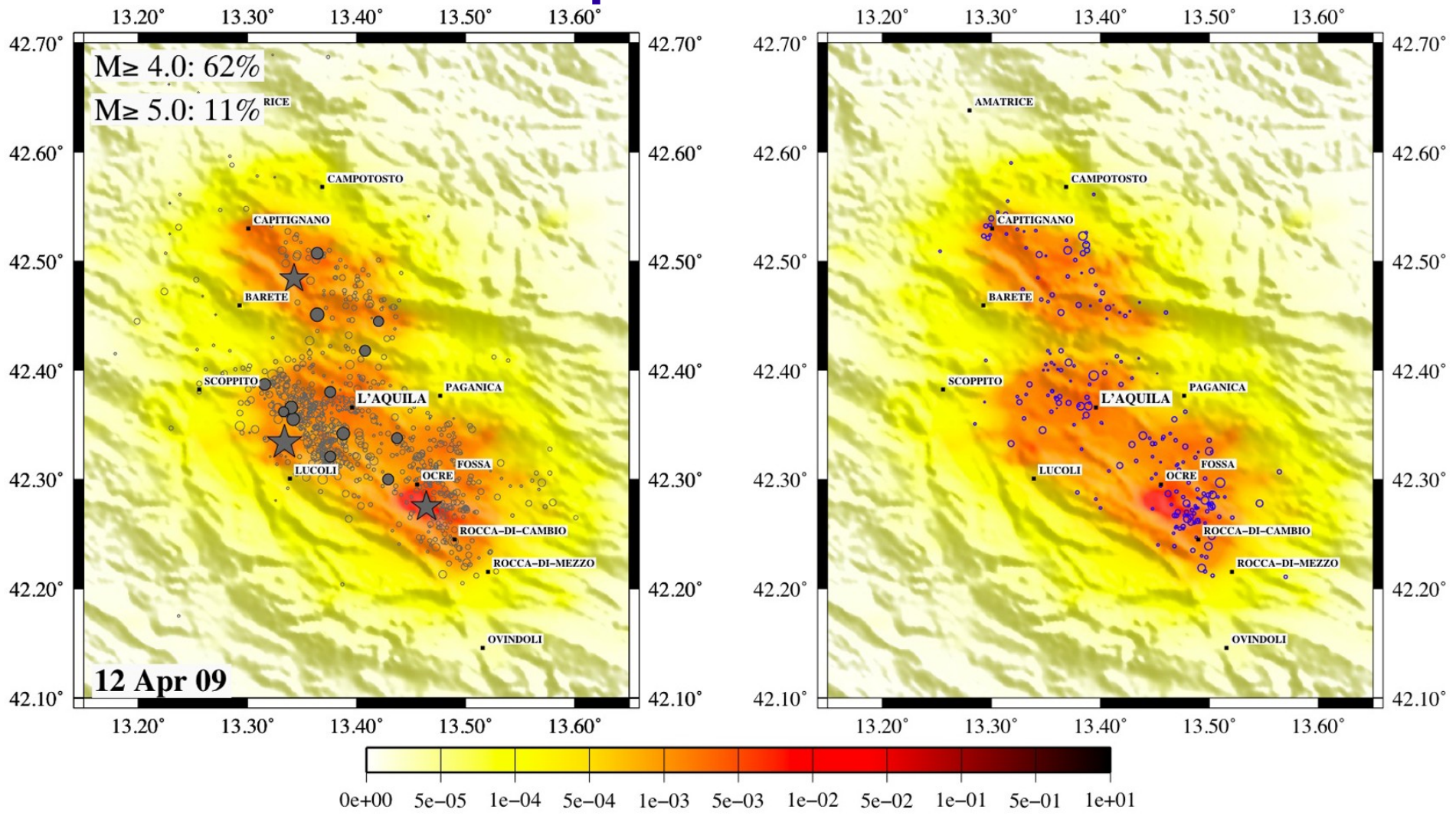
Much more to come

Real-time next-day earthquake forecasts

In the wake of the L'Aquila earthquake (6 April 2009), forecasts were constructed using an ETAS model and were issued each day at 0800.

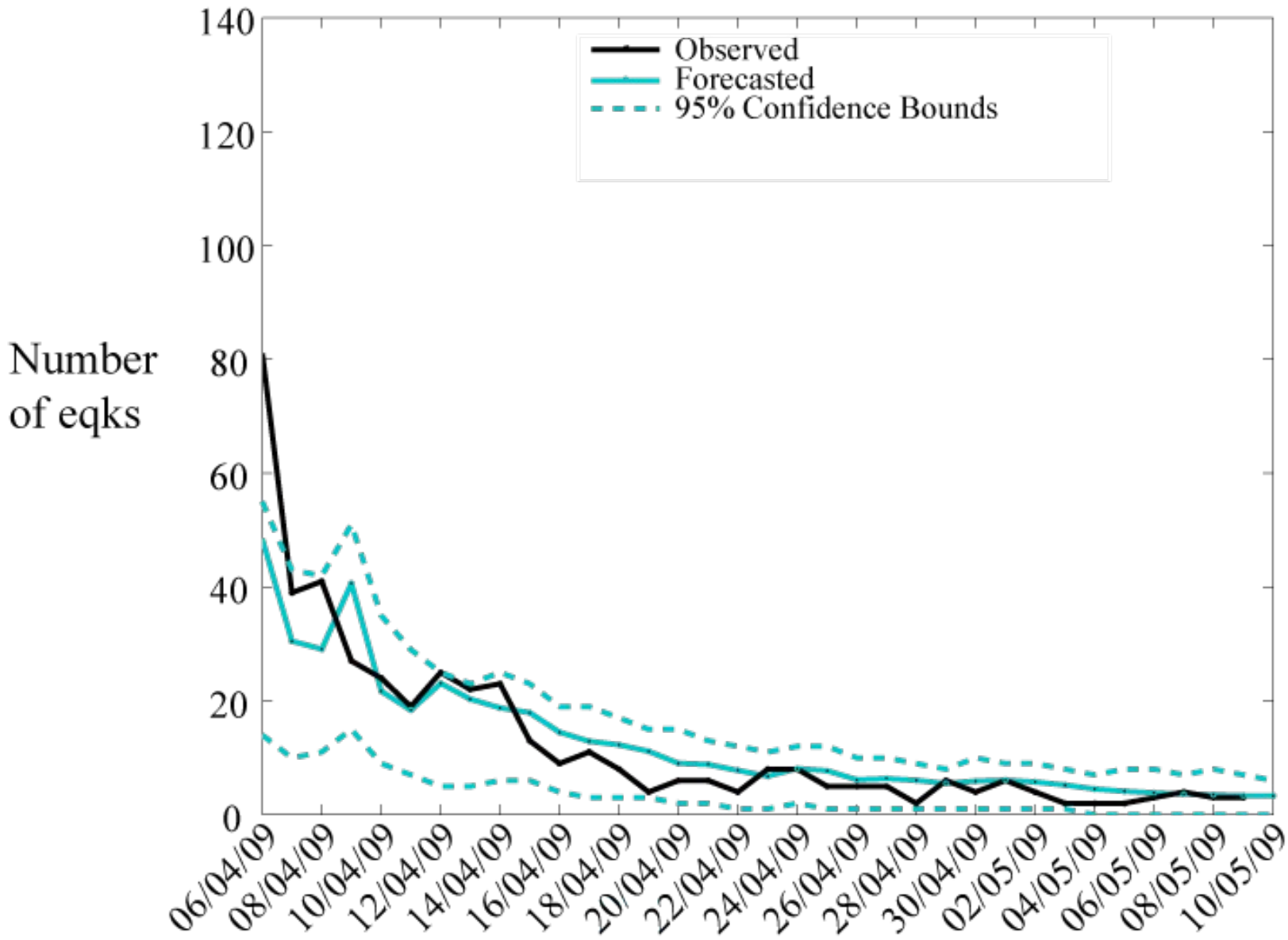
Forecasts were stated as the expected number of eqks with $M \geq 4$ for the following 24-hr period.

Example forecast

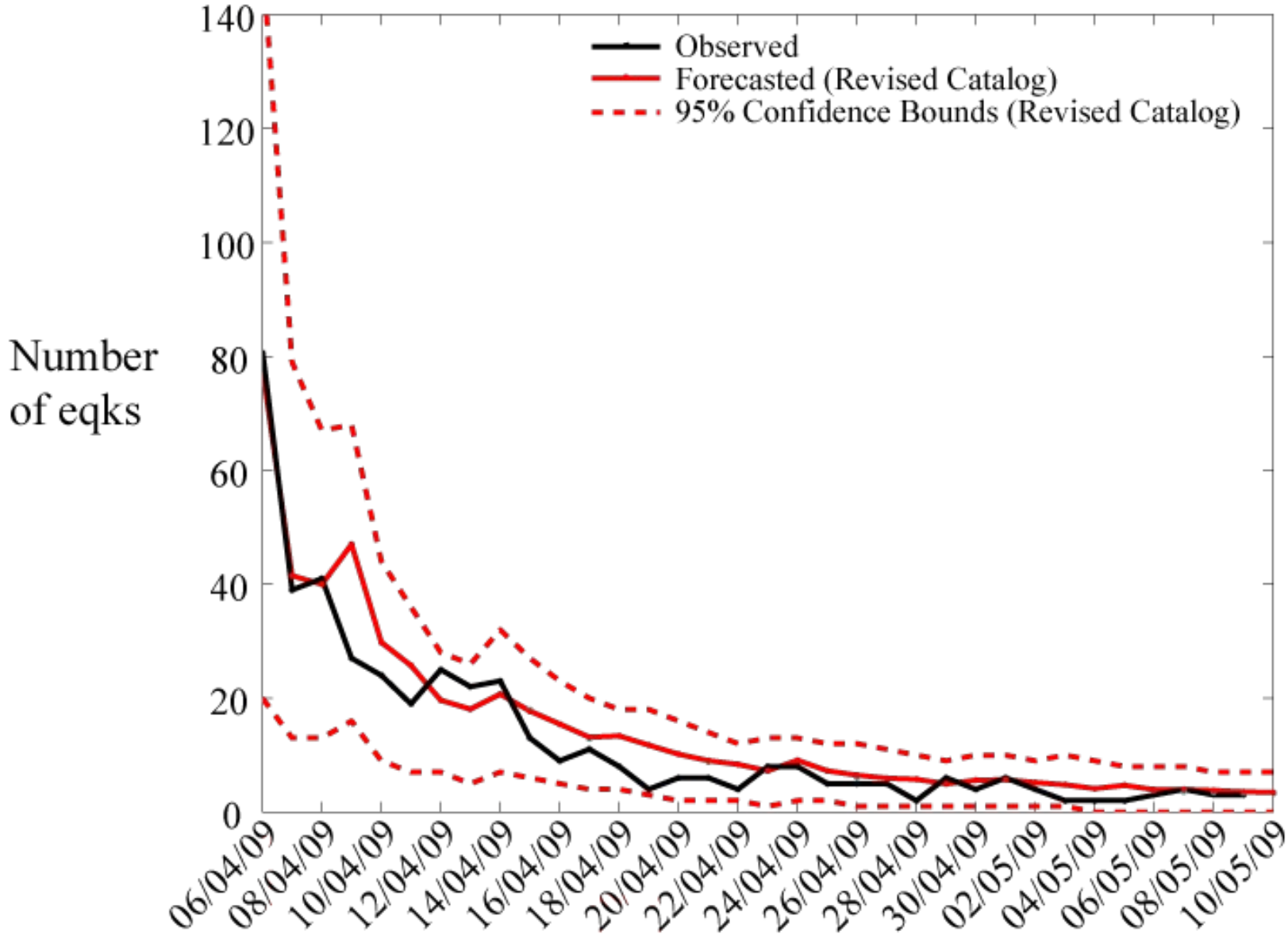


How good were these forecasts?

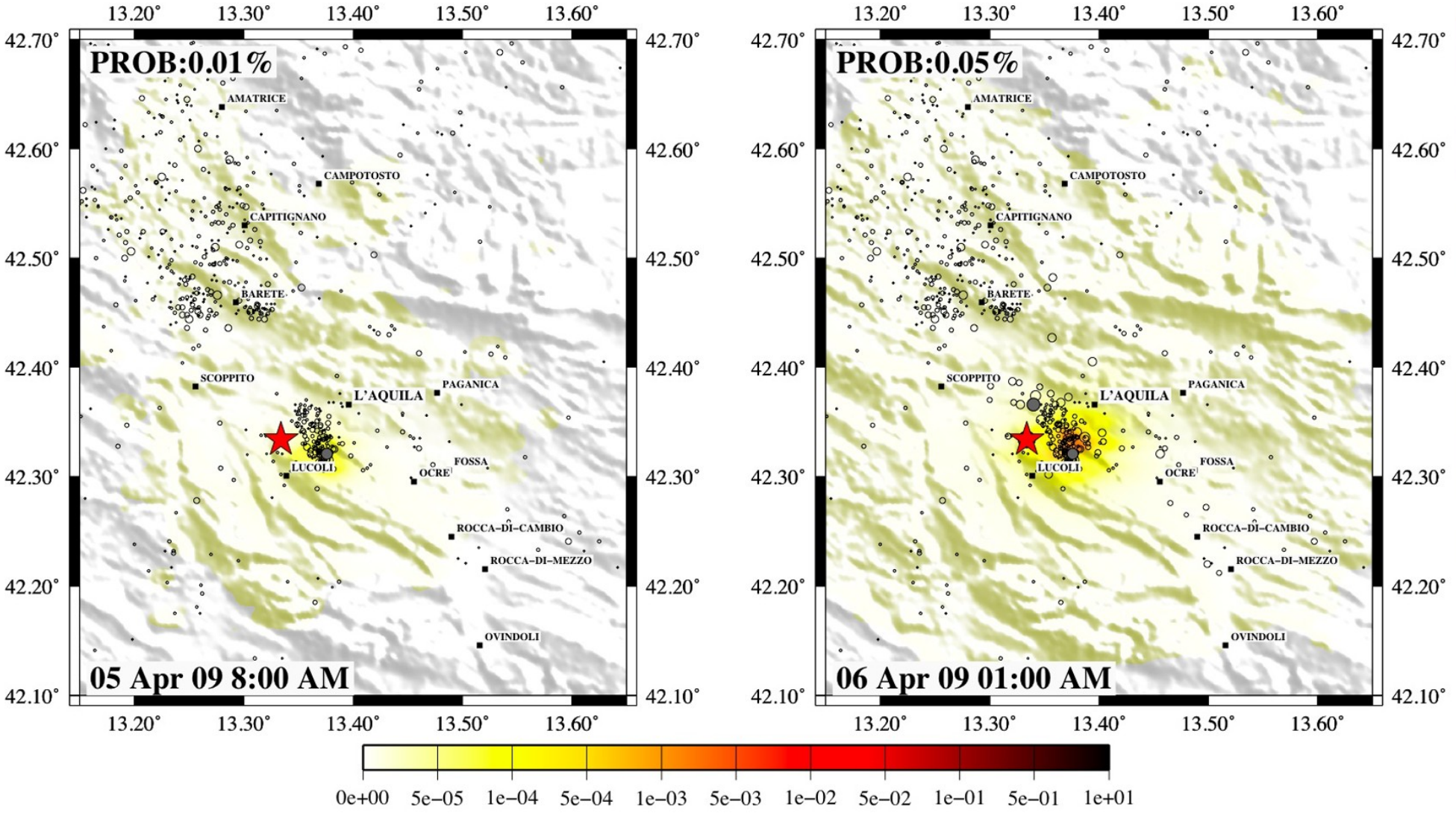
Rate analysis



Rate analysis



Could the model have effectively forecast the L'Aquila eqk?



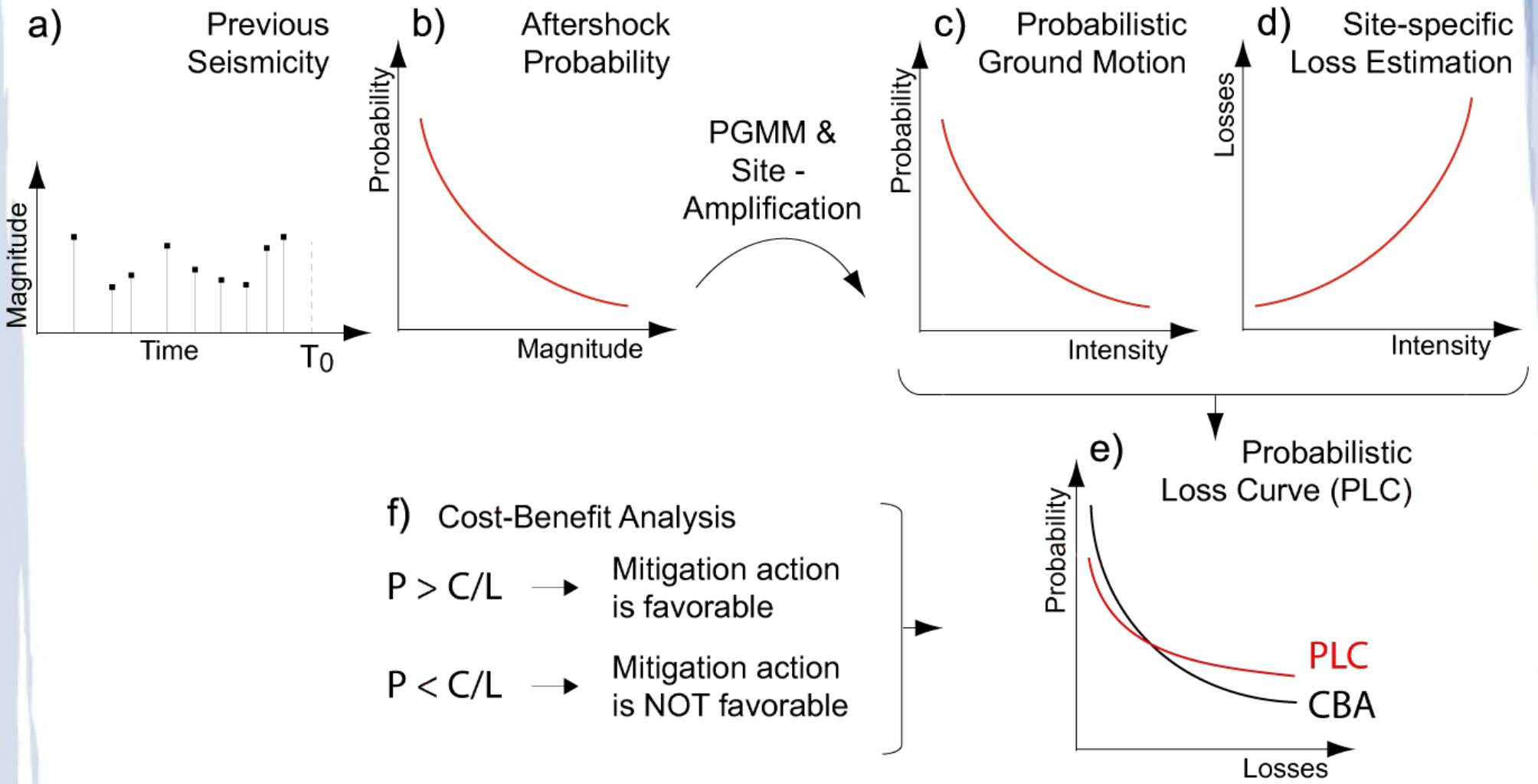
More generally, could/should something have been done?

Consider simple cost-benefit analysis approach:

- Cost, C, of mitigation action
- Financial losses, L, due to risk
- Probability, P, of risk

Mitigation action is favorable if $P>C/L$.

Probabilistic loss workflow



Method

Cost-Benefit Approach for Aftershock Risk Estimation

$$\frac{C}{L} = \frac{persons\ evacuated * socio-economic\ cost\ per\ person\ per\ day * days}{fatalities * amount\ willingly\ paid\ for\ avoided\ fatality}$$

- **Socio-economic costs** here defined by total cost of **evacuation of buildings** (costs such as closing businesses; losing working hours; broadcasting the alarm; and providing facilities, board, and lodging for people)
- **Amount willingly paid for avoided fatality:** average societal value of a life. This number should be defined by the decision makers and is often controversial **– but unavoidable!**

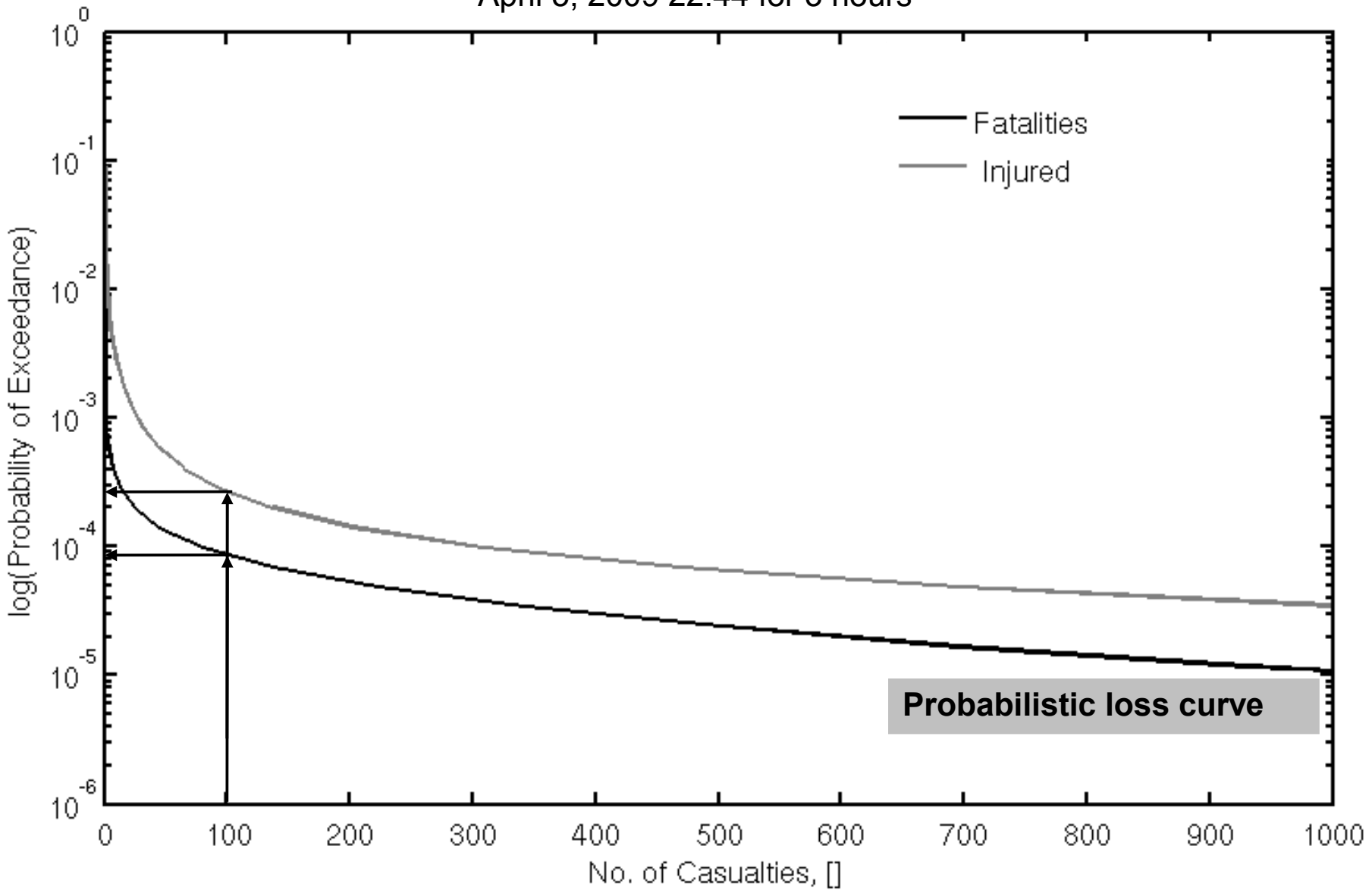
Application to L'Aquila eqk

- Reasenberg & Jones aftershock probabilities
- Seismicity: 1 January – 6 April 2009 (before L'Aquila M_w6.2), M_w>=2.5
- Population data: 2008/2009
- Building stock according to Quakeloss
- Mitigation action: Evacuation of buildings of EMS-98 vulnerability classes A and B

Loss estimate for M_w6.2 l'Aquila earthquake:
Plausible range: 297 – 596 Fatalities
Most probable: 430 Fatalities

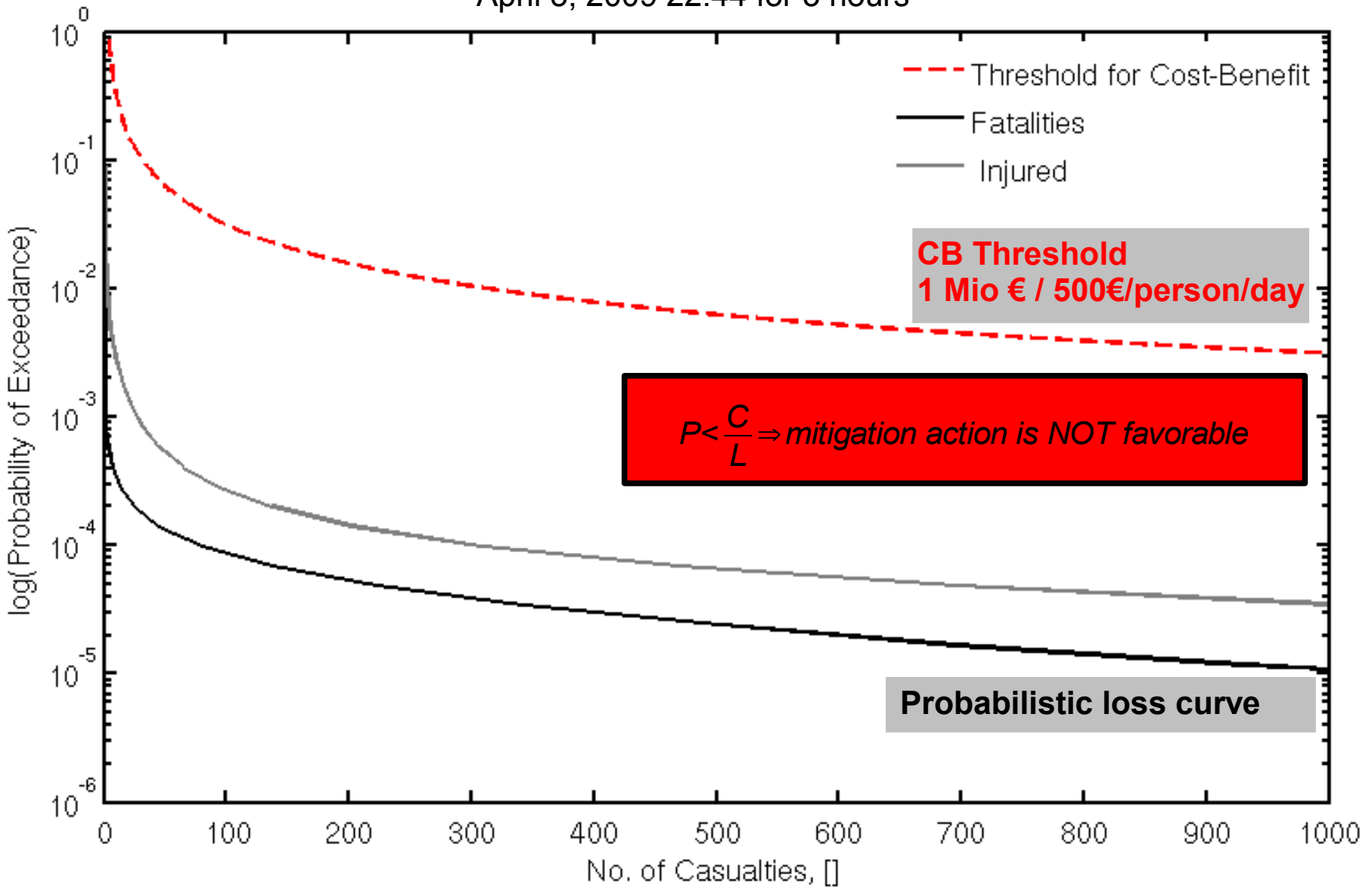
Losses for L'Aquila city

April 5, 2009 22.44 for 3 hours



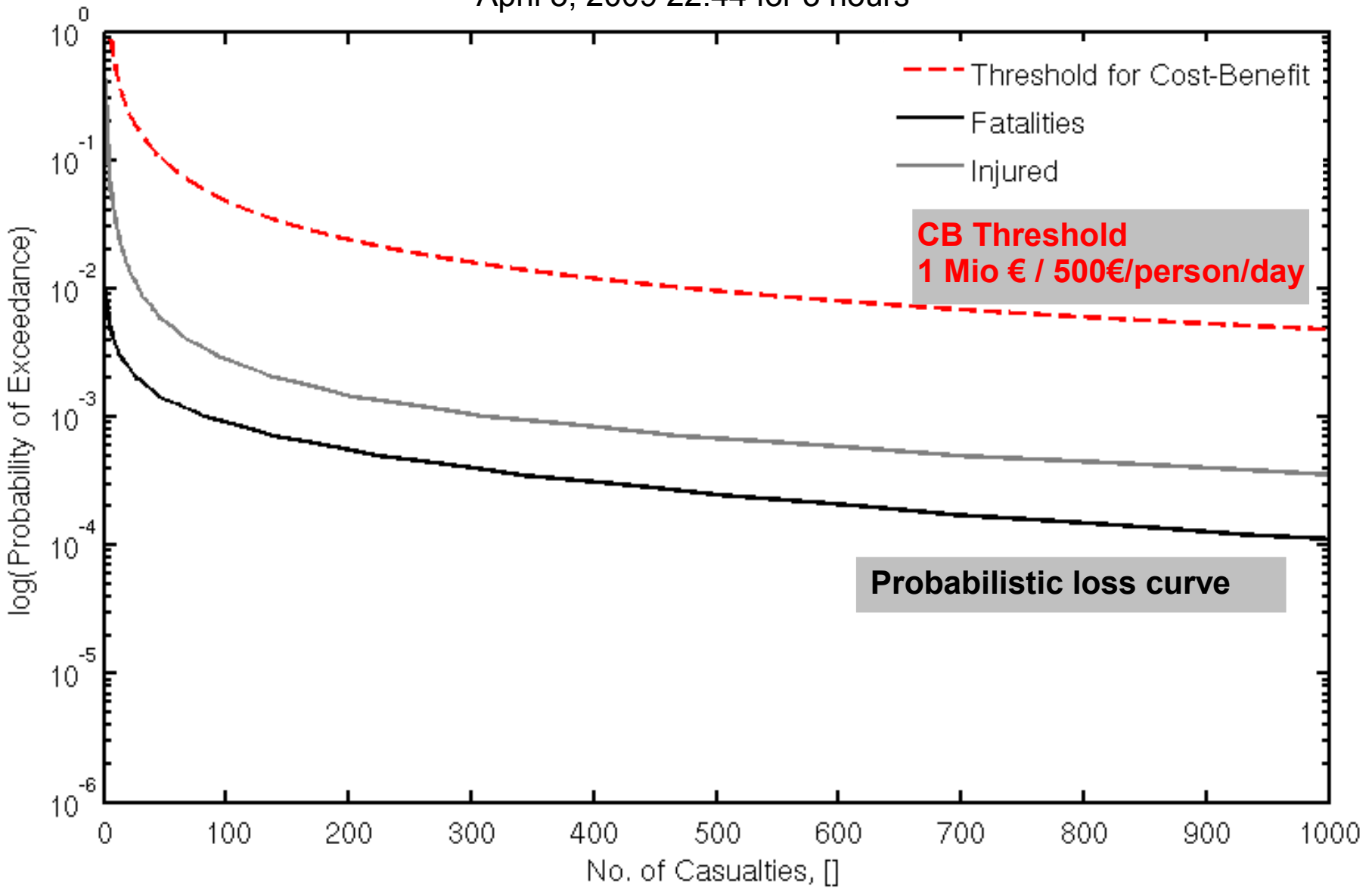
Cost-benefit for L'Aquila city

April 5, 2009 22.44 for 3 hours



Cost-benefit for L'Aquila region

April 5, 2009 22.44 for 3 hours



Cost-benefit for L'Aquila city

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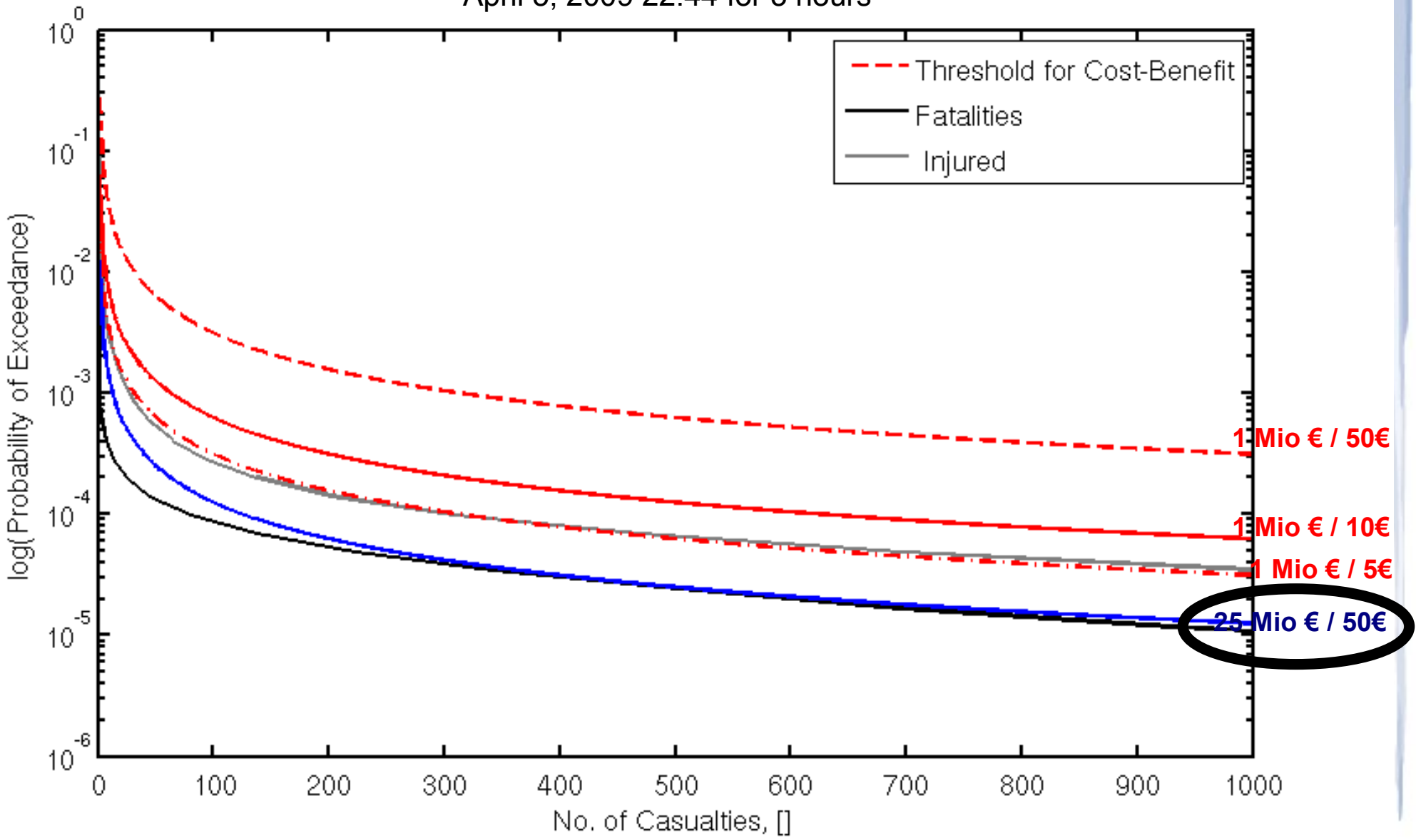

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Thank you.

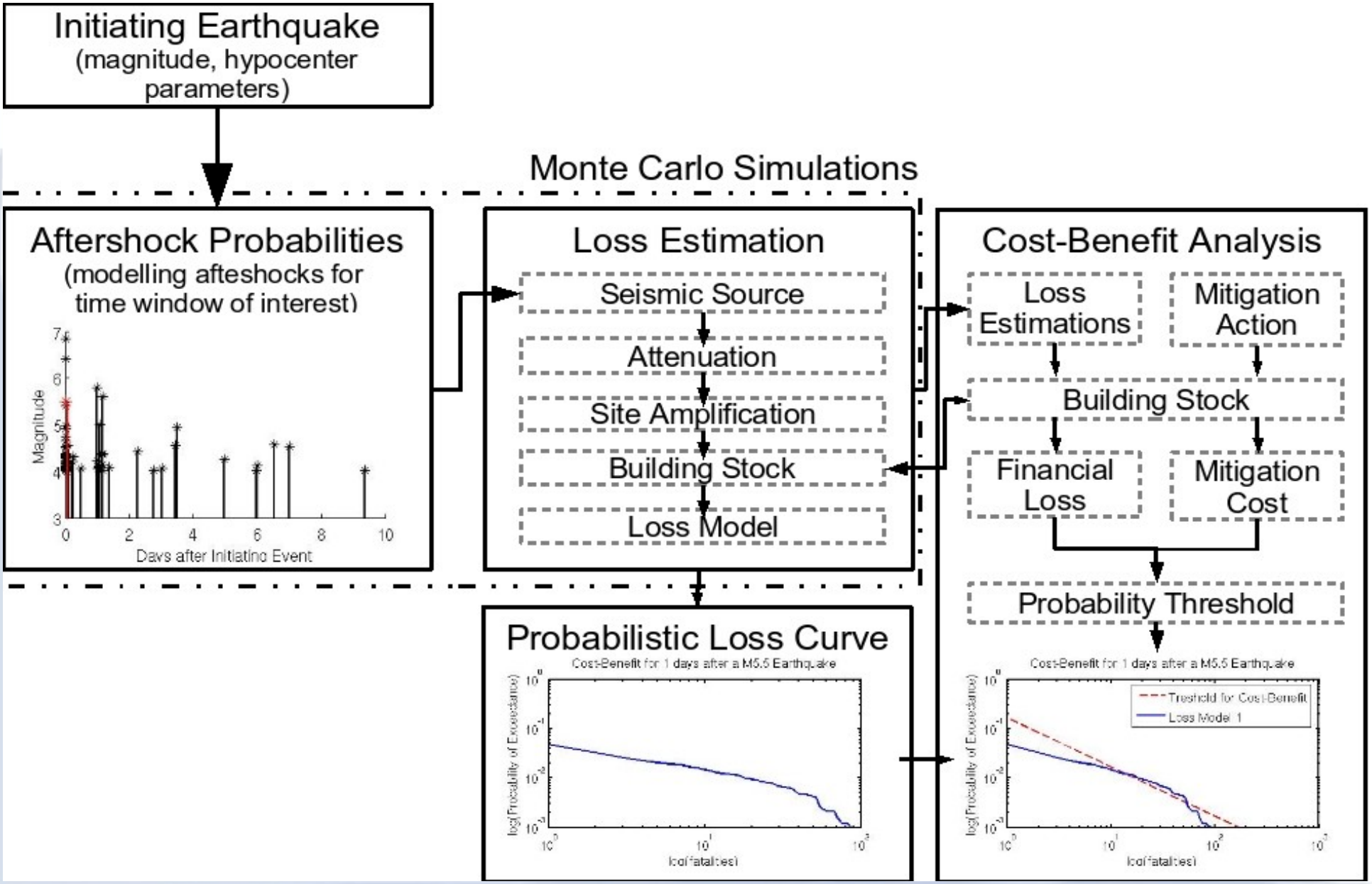
RI/ALM interpretation

1) Based on the observed joint likelihood, RI is superior to ALM.

2) Based on the L-test, however, observation is inconsistent w/ RI and consistent w/ ALM.

This is a matter of perspective: 1) asks the opinion of the observation, 2) asks the opinion of the forecasts. There is an analogy to dating here.

Method


Initiating Earthquake
(magnitude, hypocenter parameters)
Monte Carlo Simulations
Aftershock Probabilities
(modelling afteshocks for time window of interest)
Magnitude
Days after Initiating Event
Loss Estimation
Seismic Source
Attenuation
Site Amplification
Building Stock
Loss Model
Cost-Benefit Analysis
Loss Estimations
Mitigation Action
Building Stock
Financial Loss
Mitigation Cost
Probability Threshold
Probabilistic Loss Curve
Cost-Benefit for 1 days after a M5.5 Earthquake
log(Probability of Exceedance)
log(fatalities)
Cost-Benefit for 1 days after a M5.5 Earthquake
Treshold for Cost-Benefit
Loss Model 1
log(Probability of Exceedance)
log(fatalities)