Ay/Ge117
winter 2021
Bayesian Statistics
& Data Analysis

Aftershocks decay fitting with MCMC ensemble sampling: Omori-Utsu decay constant and heat flow relation?

Yuan-Kai Liu, California Institutde of Technology
ykliu@caltech.edu.sa

Aftershocks occurrence delay

Aftershocks are one of the most prominent expressions of relaxation processes induced by abrupt stress perturbations from the neighboring major earthquakes (EQs). The aftershocks frequency decays with time and stress relaxation.

Omori-Utsu law describes the decay of the frequency of aftershocks with the reciprocal of time after a mainshock. This power-law empirical relation was first described by Fusakichi Omori in 1894. It takes the form as:

$$n(t) = \frac{K}{(t+c)^p}$$

- t - time lapse from mainshock
- n - number of aftershocks at some time
- K - productivity constant
- c - lag time after mainshock before decaying
- **p - power-law decay constant**

Earth's heat flow relates to the stress relaxation processes in Earth, thus can affect the speed of aftershocks decay

Objective and Dataset

Examine more recent aftershock datasets and contrain the Omori law parameters to validate previously propsed scaling relation between parameters and heat flow.

Get parameters uncertinaties using Markov Chain Monte Carlo (MCMC) sampling which were not provided via usual way of doing this (standard maximum likelihood estimator).

Dataset of the earthquakes
The following mainshock-aftershocks datasets are obtained from the Northern California Earthquake Data Center:

- 1985 M6.1 Kettleman Hills earthquake
- 1989 M6.9 Loma Prieta earthquake
- 2004 M6.0 Parkfield earthquake
- 2011 M5.7 Prague earthquake
- 2019 M7.1 Ridgecrest earthquake

(M = magnitude)

Minimum magnitude: only analyze EQs larger than magnitude 1.5

Maximum radius: only analyze EQs within this radius from maishock

$$r = 10^{0.25M-0.22} \quad \text{[km]}$$

Demonstration of 2004 M6.0 Parkfield Earthquake

Earthquakes distributions:
Figure 1 and 2 shows the aftershocks distribution in space and in time after the 2004 M6.0 Parkfield (CA) earthquake. The triggered aftershocks after the M6.0 mainshock decays with time following a power-law.

Figure 1

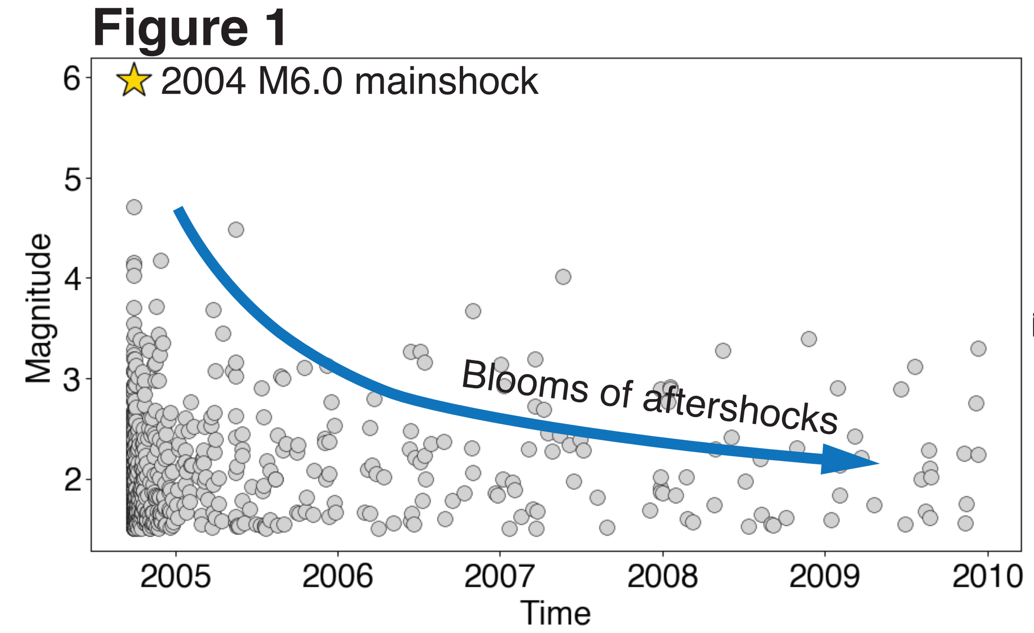
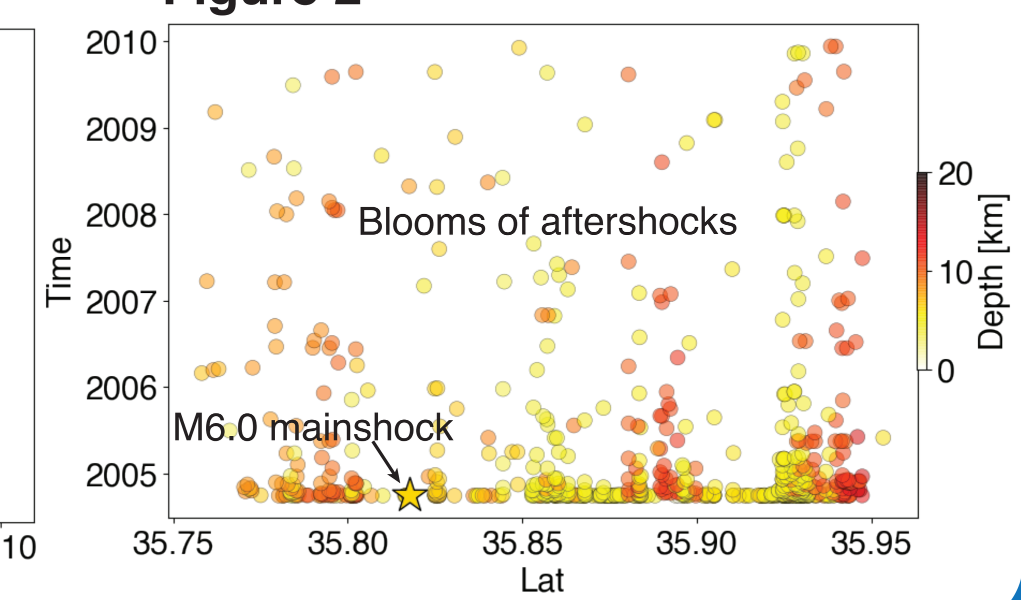


Figure 2



Parameters est. (1): Maximum likelihood estimation

- **Maximum likelihood estimator (MLE):** MLE function of the Omori-Utsu law from Ogata (1983)
- **Minimization:** *scipy.optimize.minimizer* finds the best-fit solution satisfying MLE
- The solution serves as a starting point in the MCMC sampling method

Parameters est. (2): Markov Chain Monte Carlo Ensemble sampler

Bayesian prior:
a uniform prior within a range:
$10^{-4} \le c \le 2.0$
$2.0 \le K \le 10^4$
$0.2 \le p \le 2.0$

MCMC ensemble sampler:
32 walkers, each with 5000 steps to sample the posterior probability distribution.

Parameter ensemble:
Randomly draw 200 samples of the MCMC solutions (orange lines in Figure 3)

Figure 3 Example corner plot for 2004 Parkfield EQ

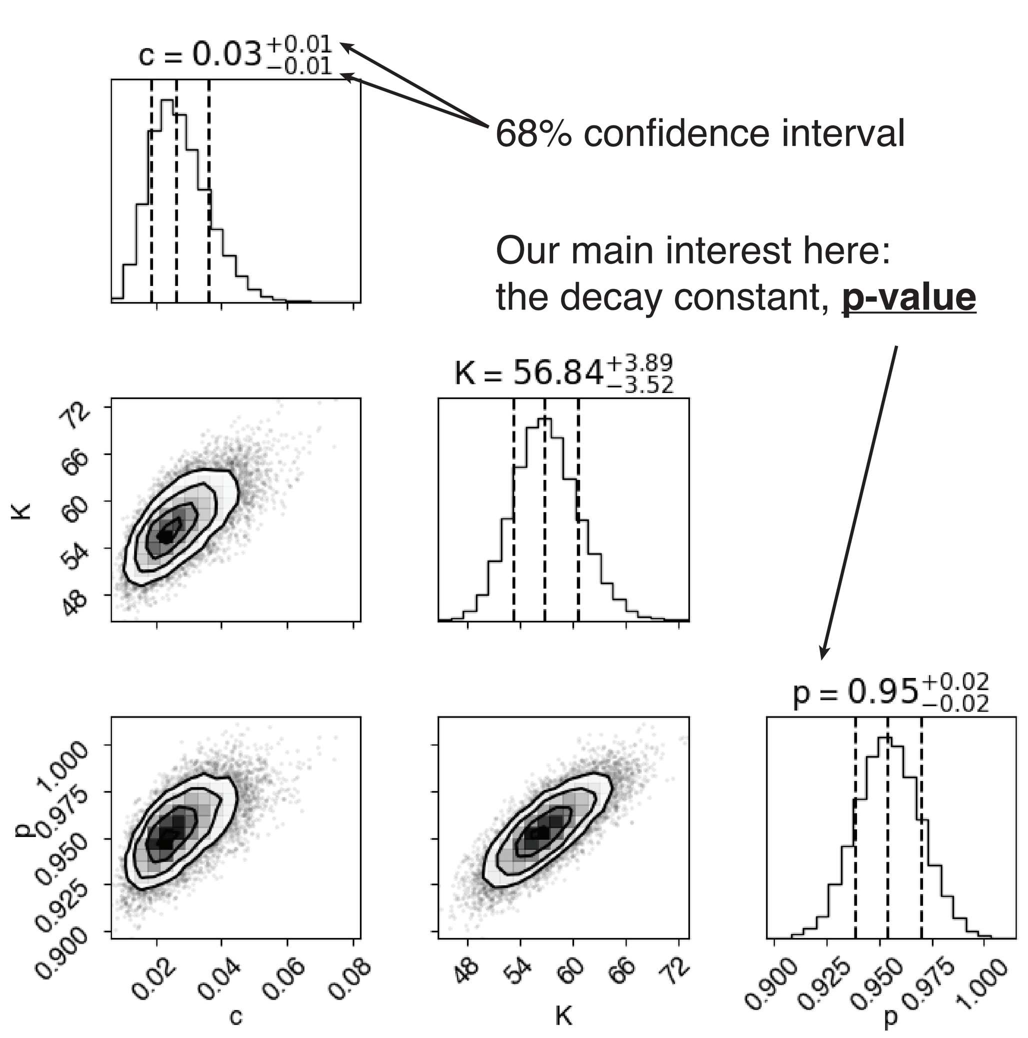
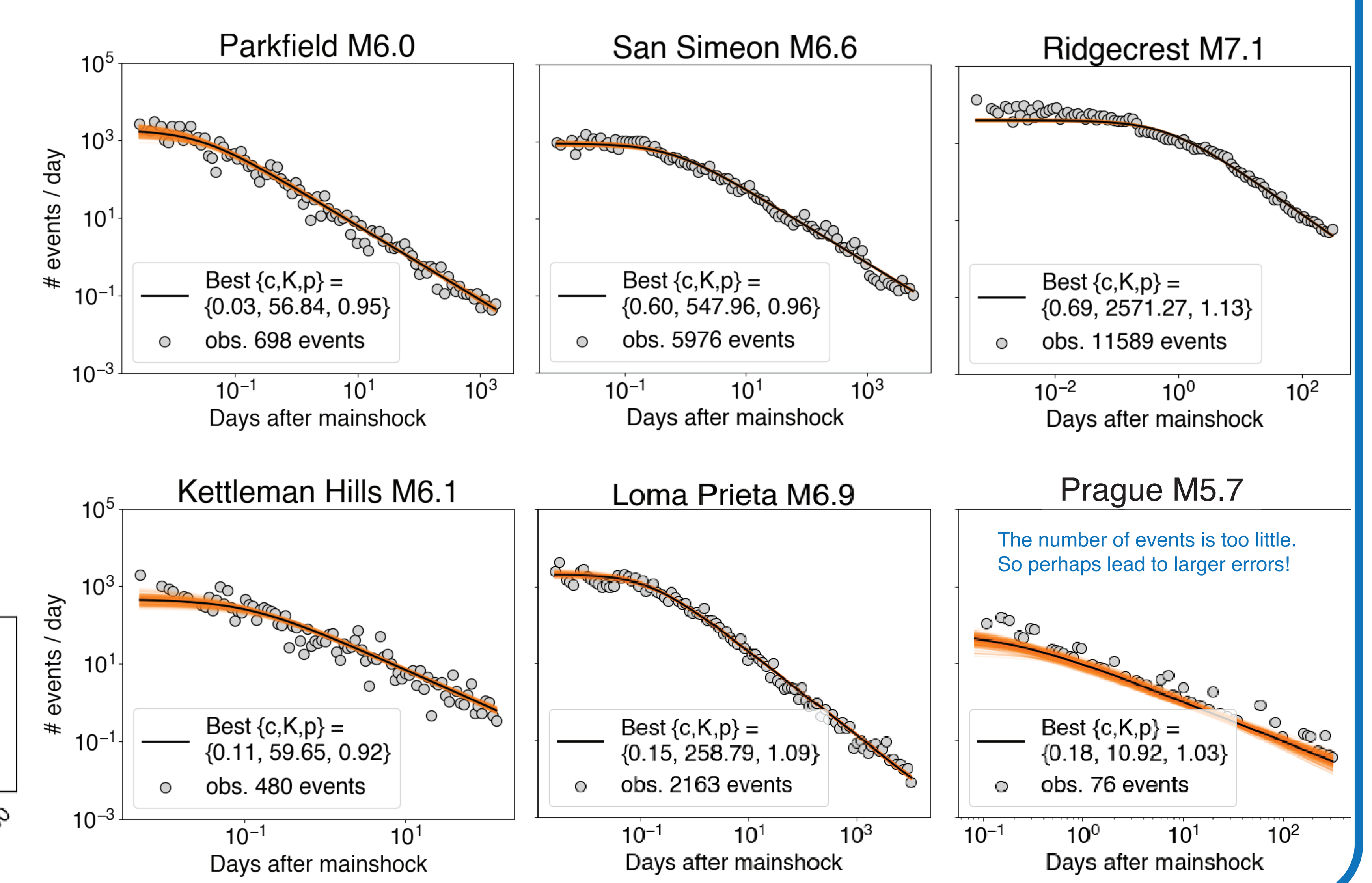


Figure 4 Constrained final models match the datasets quite well



Result: Heat flow relation

Figure 5 California heat flow map

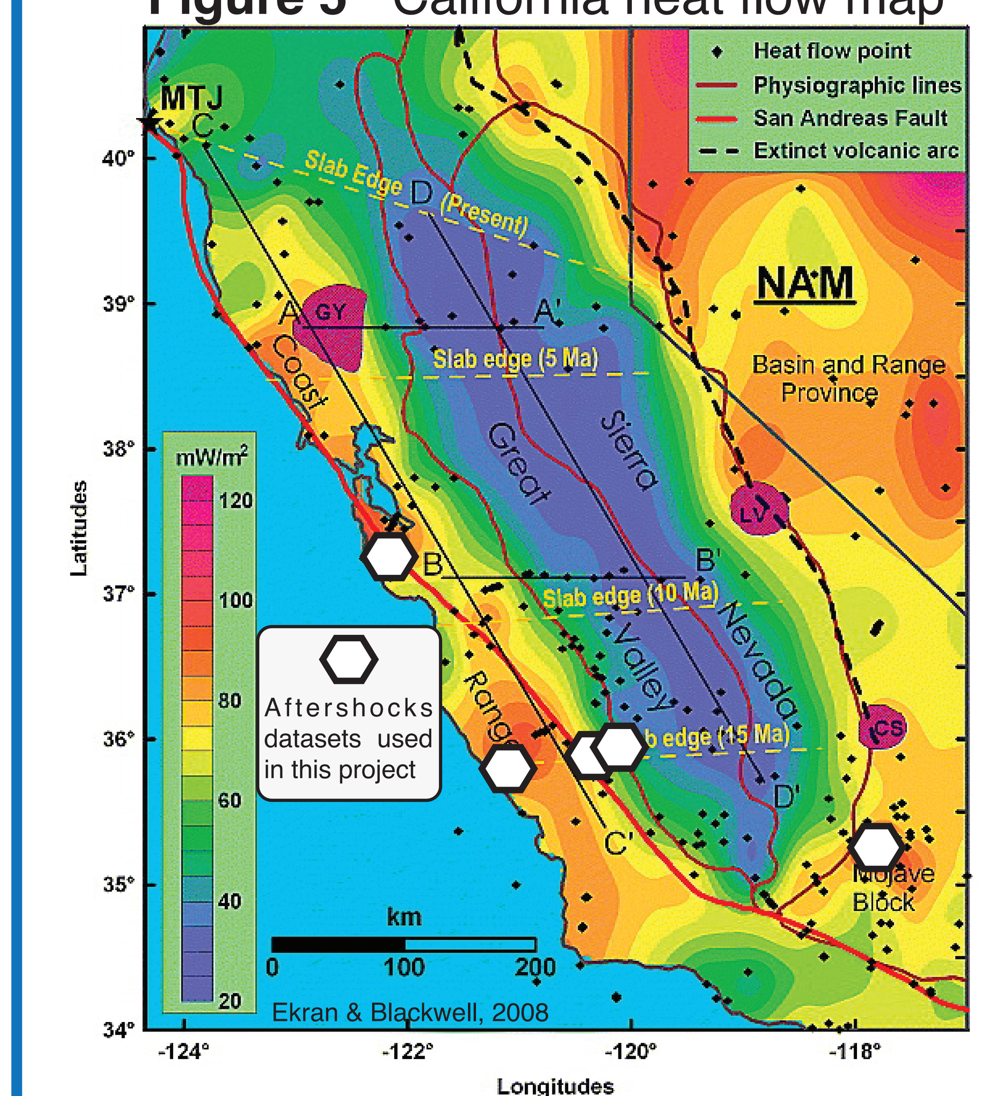
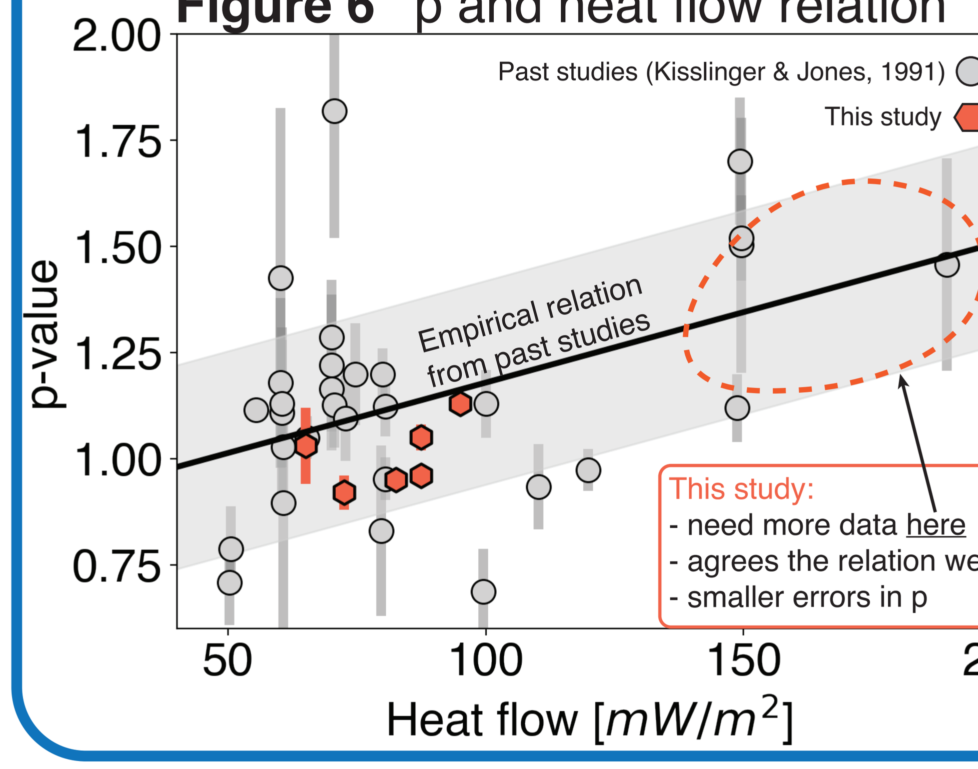


Figure 6 p and heat flow relation



Conclusion

- This approach provides robust estimates and uncertainties of the decay parameters
- New data shows less uncertainties compared to studies in 90's
- More recent aftershocks data recorded at high heat flow regions shoud be analyzed to strengthen the heat-flow relation

Method paper & References