Statistical distributions of seismicity in the Cooper Basin geothermal field
– a way towards predictive models of induced seismicity

Barth, A[1]., Carstens, P.[2], Baisch, S.[2]

KIT, Geophysical Institute

1) Karlsruhe Institute of Technology, Germany

2) Q-con GmbH, Bad Bergzabern, Germany

2nd Induced Seismicty Workshop

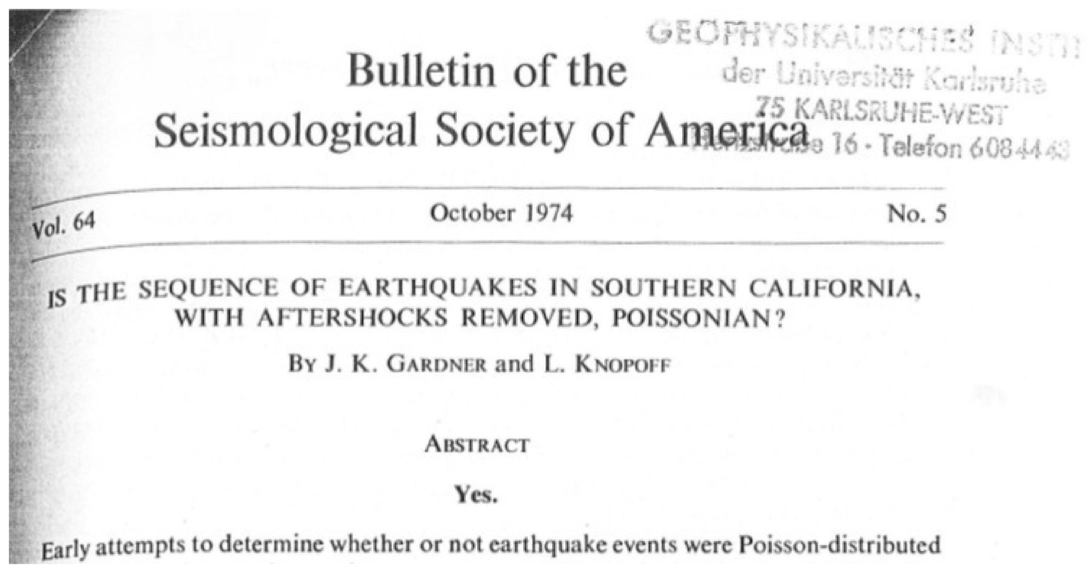
Davos, 14-17 March 2017

Motivation

- Seismic hazard estimation relies on specific statistical properties
- Tectonic seismicity has proven to fullfil criteria

Motivation

- Seismic hazard estimation relies on specific statistical properties
- Tectonic seismicity has proven to fullfil criteria



Bulletin of the
Seismological Society of America

Vol. 64 October 1974 No. 5

IS THE SEQUENCE OF EARTHQUAKES IN SOUTHERN CALIFORNIA, WITH AFTERSHOCKS REMOVED, POISSONIAN?

By J. K. Gardner and L. Knopoff

Abstract

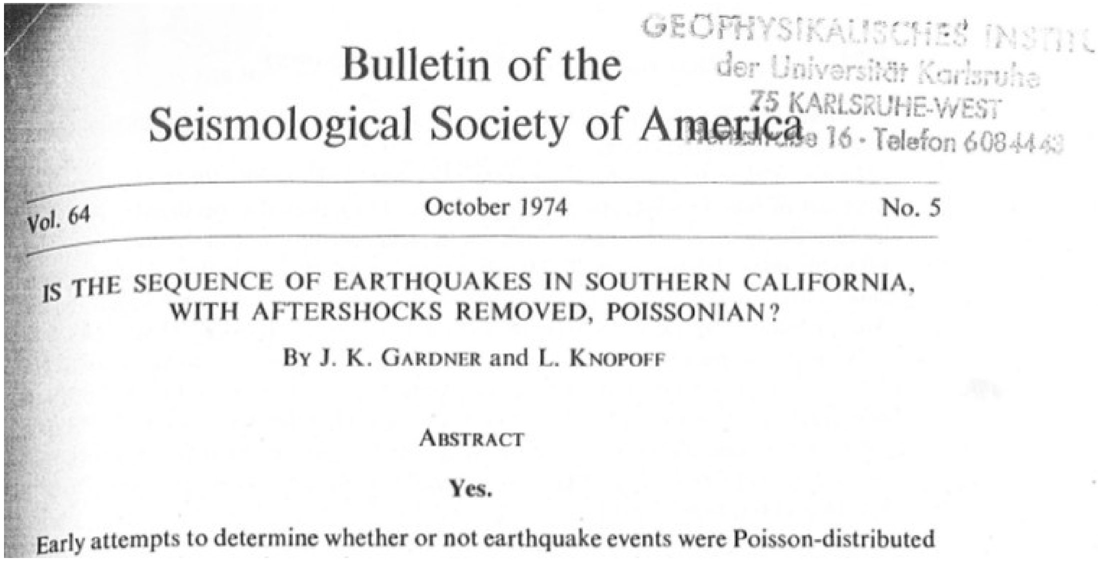
Yes.

Early attempts to determine whether or not earthquake events were Poisson-distributed

Motivation

- Seismic hazard estimation relies on specific statistical properties
- Tectonic seismicity has proven to fullfil criteria

→ **What about induced seismicity?**



Bulletin of the
Seismological Society of America

Vol. 64 October 1974 No. 5

IS THE SEQUENCE OF EARTHQUAKES IN SOUTHERN CALIFORNIA, WITH AFTERSHOCKS REMOVED, POISSONIAN?

By J. K. Gardner and L. Knopoff

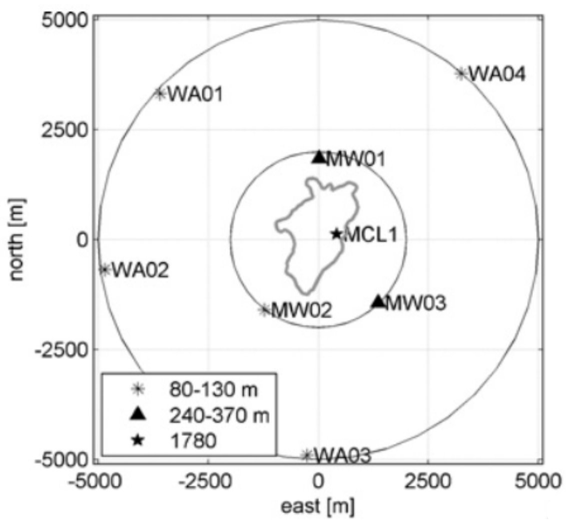
Abstract

Yes.

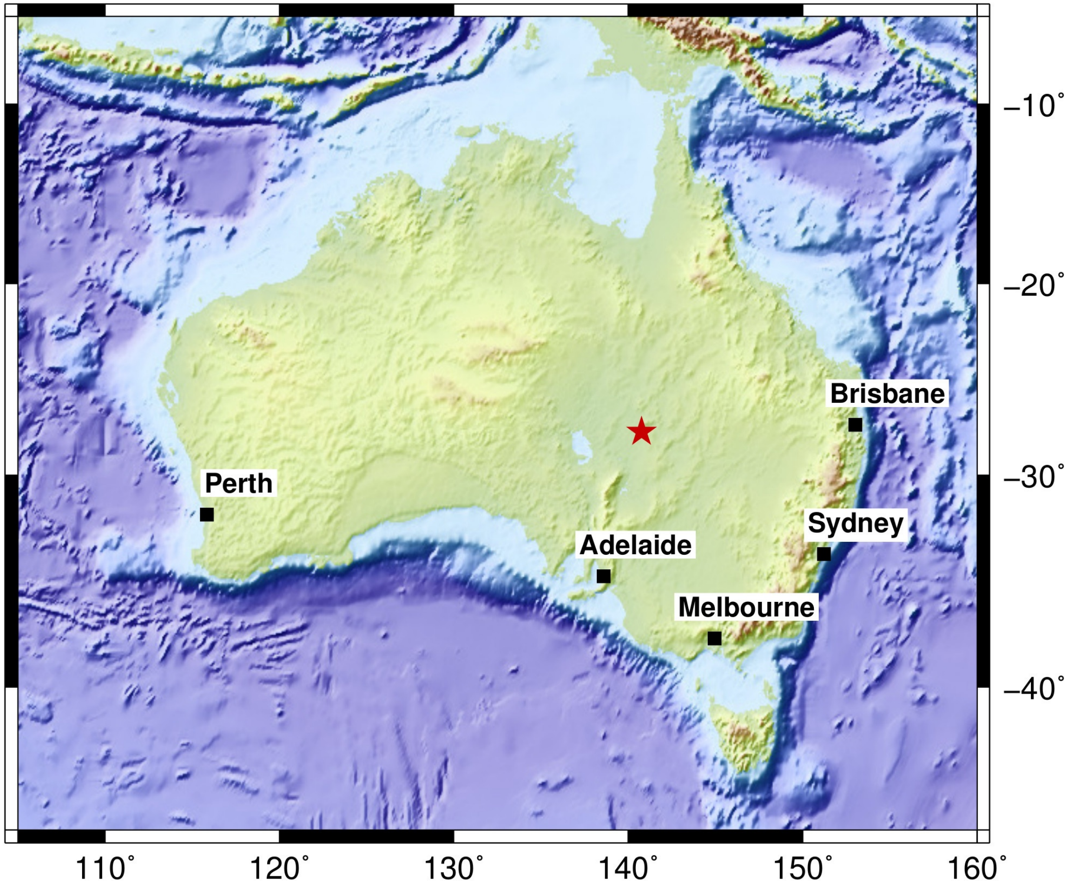
Early attempts to determine whether or not earthquake events were Poisson-distributed

Cooper Basin Geothermal Reservoir

- Seismic network
  (3 components)
  - 1 central (d = 1780 m)
  - 7 shallow (d = 80-400 m)
- 15,300 events detected

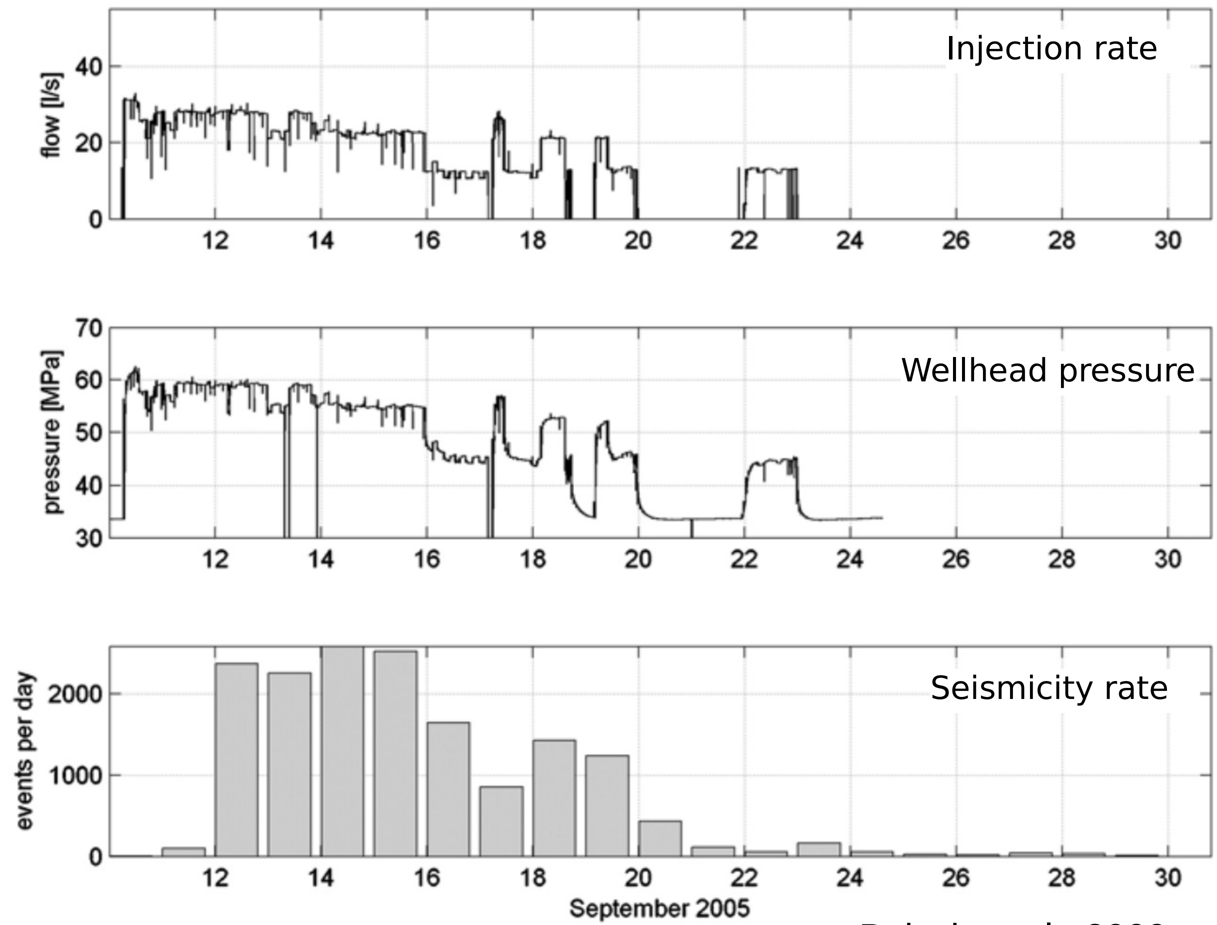


Baisch et al., 2009



Stimulation Cooper Basin

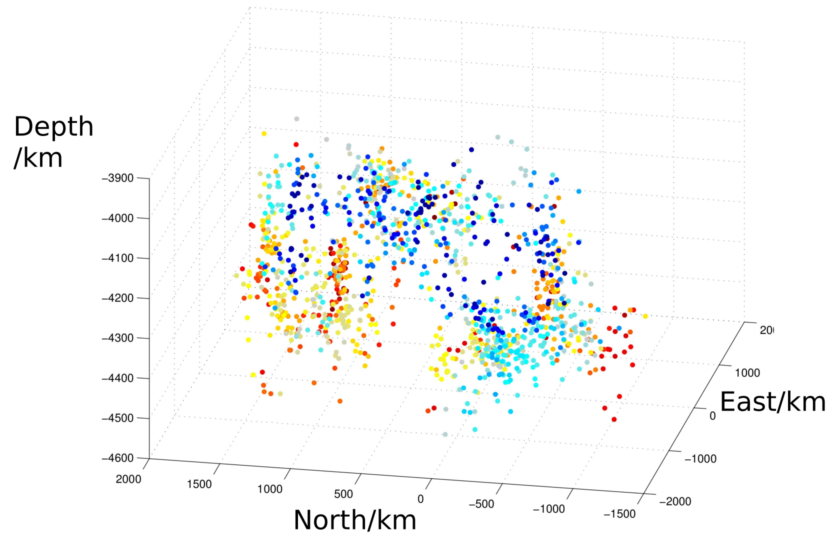
- Injection starts:
  10 September 2005
- Induced seismicity starts 22 h later

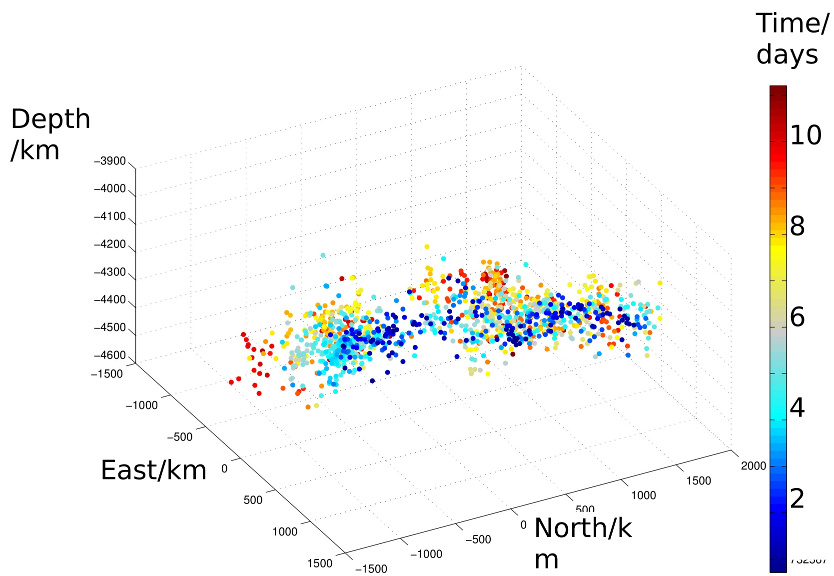


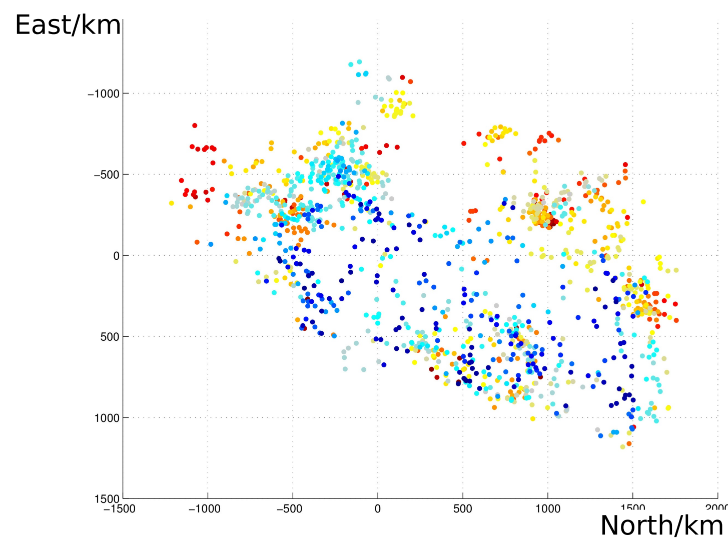
Baisch et al., 2009

Spatial distribution

- Injection starts: 10 September 2005
- 15,300 events detected
- Subset main stimulation
  8,000 events $M_L \geq -0.9$
- Planar distribution on thrust fault







Inter-event dependancies

- Tectonic seismicity
  - After-/foreshock behaviour

  - Removing after-/foreshocks (declustering) → Poisson distributed events in time

  - Declustered seismicity → Gutenberg-Richter (GR) distribution M ≥ M_C

→

$$t_A = t_0 \cdot e^{t_1 \cdot M}$$ time window

$$R_A = R_0 \cdot e^{R_1 \cdot M}$$ radius

Inter-event dependancies

- Tectonic seismicity
  - After-/foreshock behaviour

  - Removing after-/foreshocks (declustering) → Poisson distributed events in time

  - Declustered seismicity → Gutenberg-Richter (GR) distribution M ≥ M_C

→ **True for induced seismicity?**

$$t_A = t_0 \cdot e^{t_1 \cdot M}$$ time window

$$R_A = R_0 \cdot e^{R_1 \cdot M}$$ radius

Parameter study for t_A and R_A

Inter-event dependancies

- Fault dimensions (Abercrombie, 1995)

  $M = 0$ $L = 10$ m
  $M = 1$ $L = 30$ m
  $M = 2$ $L = 100$ m

- Coda length (Bakun, 1984)

  $M = 1$ $t_c = 2.3$ s
  $M = 2$ $t_c = 21$ s

- Triggering of aftershocks may be within $100 \cdot L$ *and* $10{,}000 \cdot t_c$

$$t_A = t_0 \cdot e^{t_1 \cdot M}$$ time window

$$R_A = R_0 \cdot e^{R_1 \cdot M}$$ radius

↓

Parameter study for t_A and R_A

Inter-event dependancies

- Fault dimensions (Abercrombie, 1995)

  M = 0 L = 10 m
  M = 1 L = 30 m
  M = 2 L = 100 m

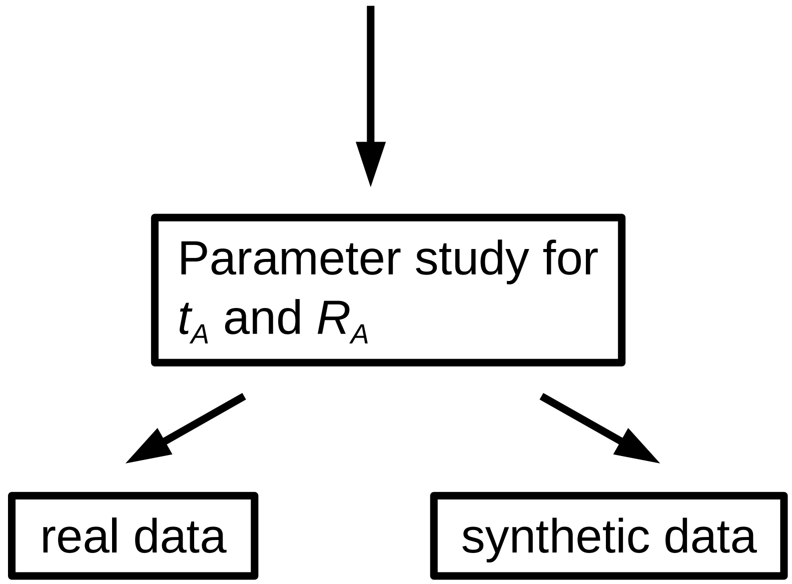
- Coda length (Bakun, 1984)

  M = 1 t_c = 2.3 s
  M = 2 t_c = 21 s

- Triggering of aftershocks may be within 100·L *and* 10,000·t_c

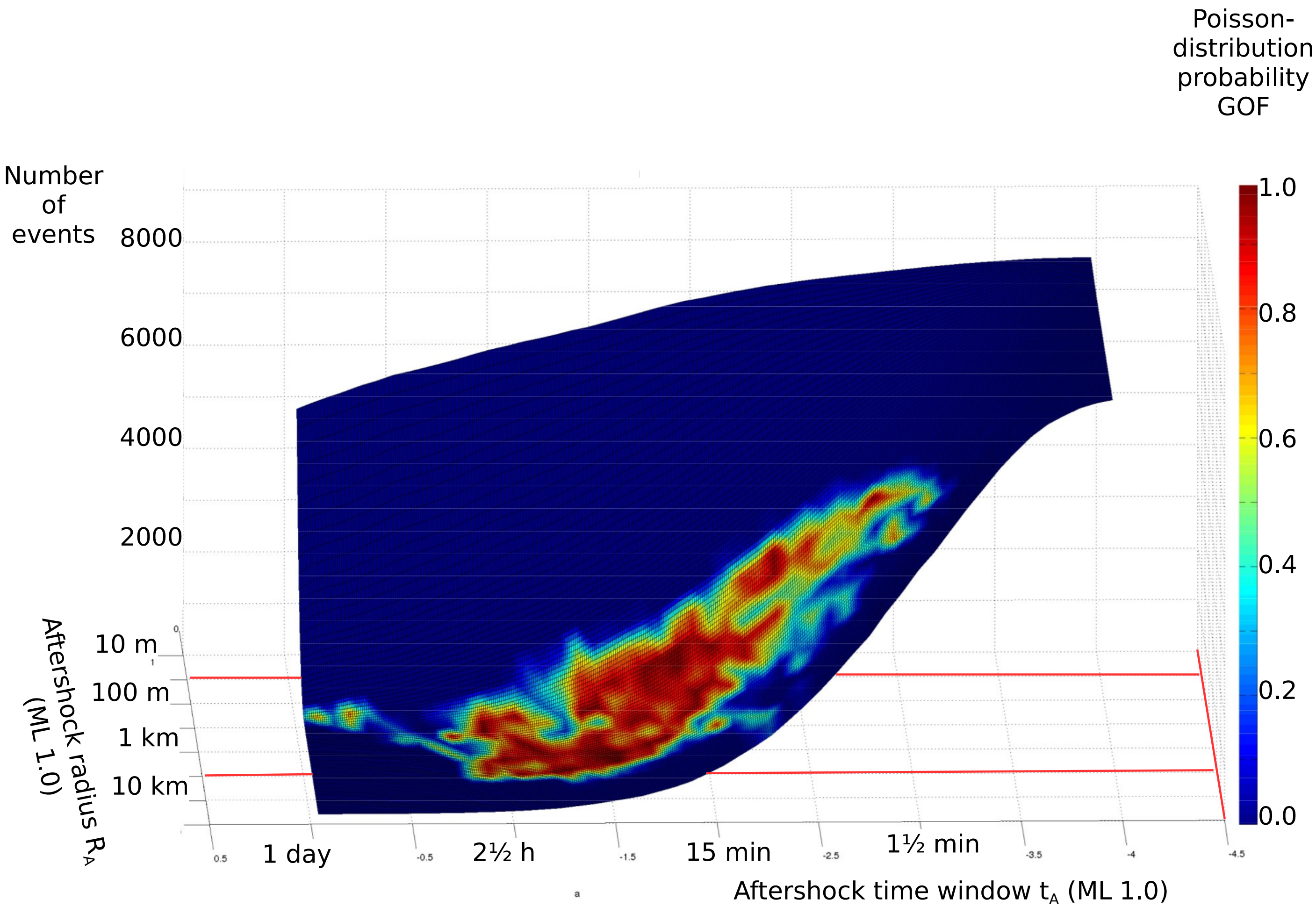
$$t_A = t_0 \cdot e^{t_1 \cdot M}$$ time window

$$R_A = R_0 \cdot e^{R_1 \cdot M}$$ radius



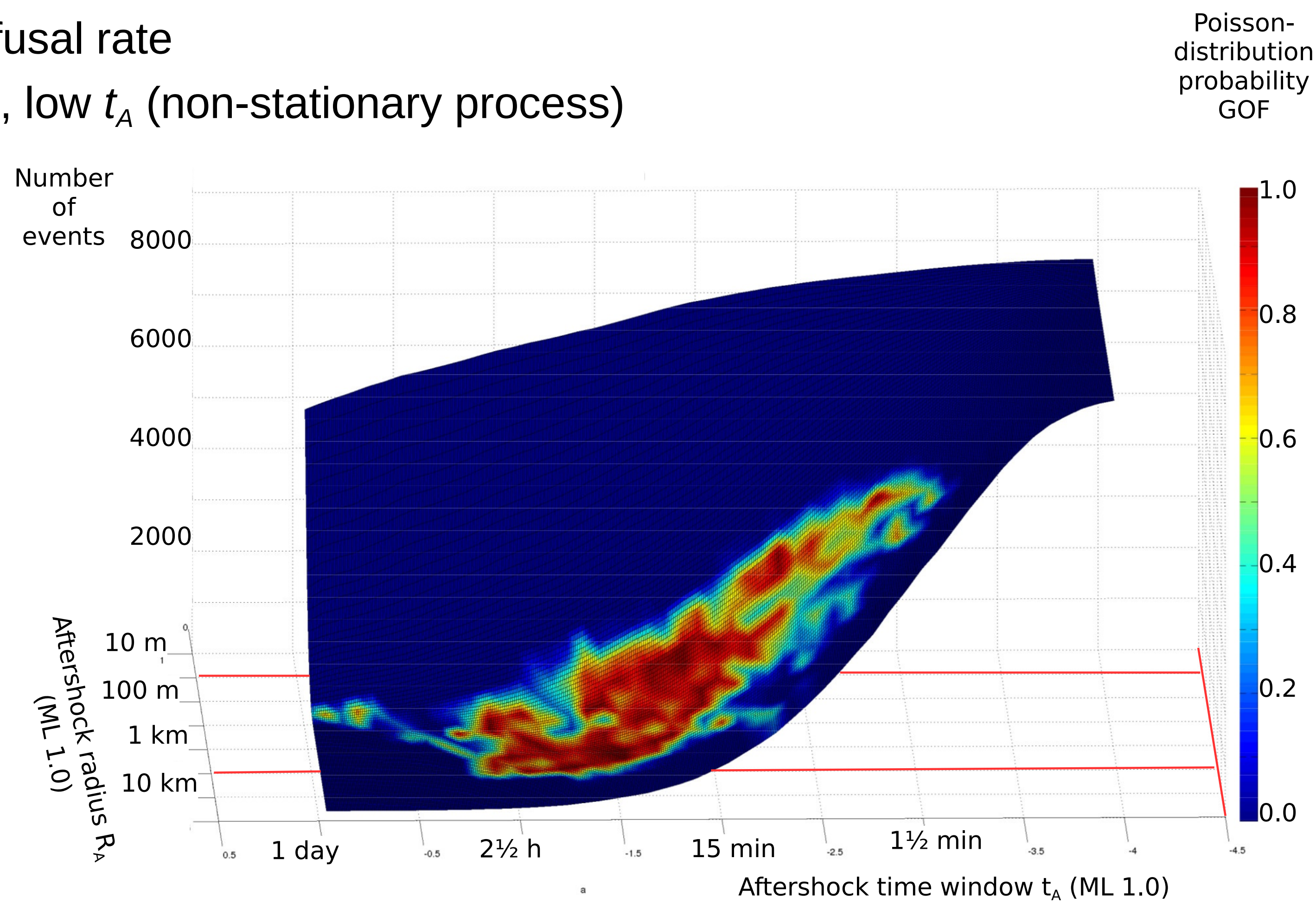
Stimulation 2005

- Poisson-distribution



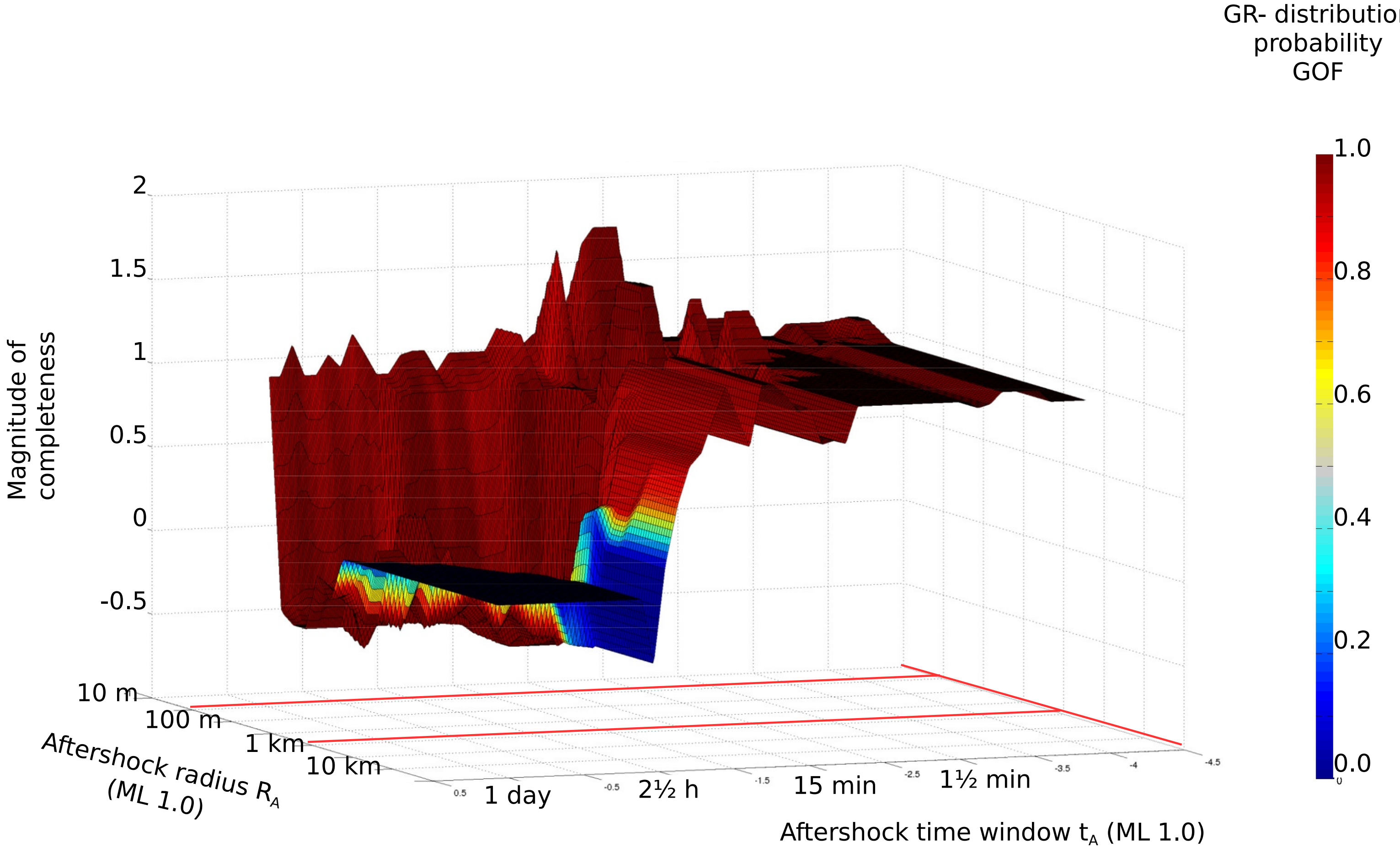
Stimulation 2005

- Poisson-distribution → inherent
  - for high refusal rate
  - for high R_A, low t_A (non-stationary process)



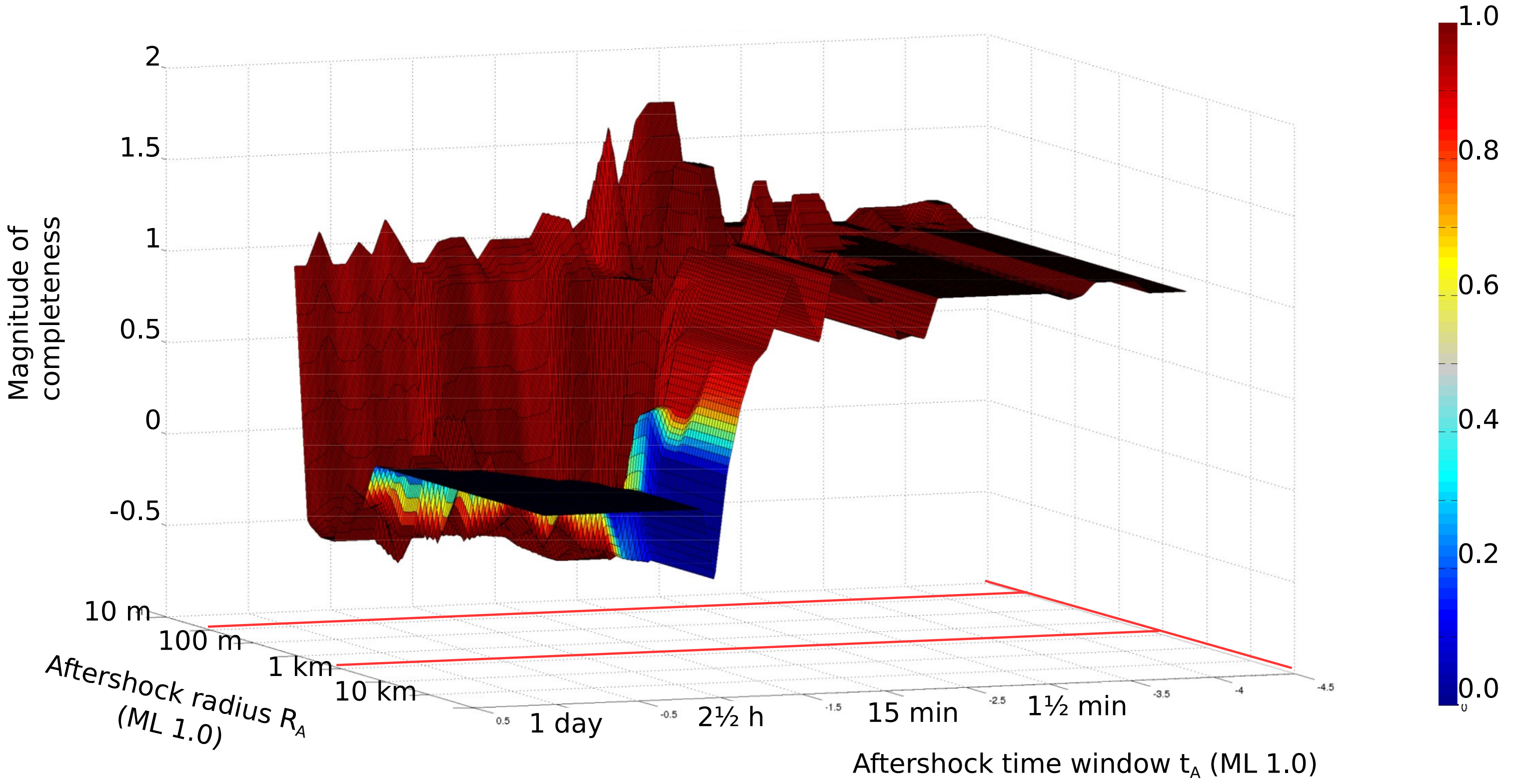
Stimulation 2005

- GR-distribution



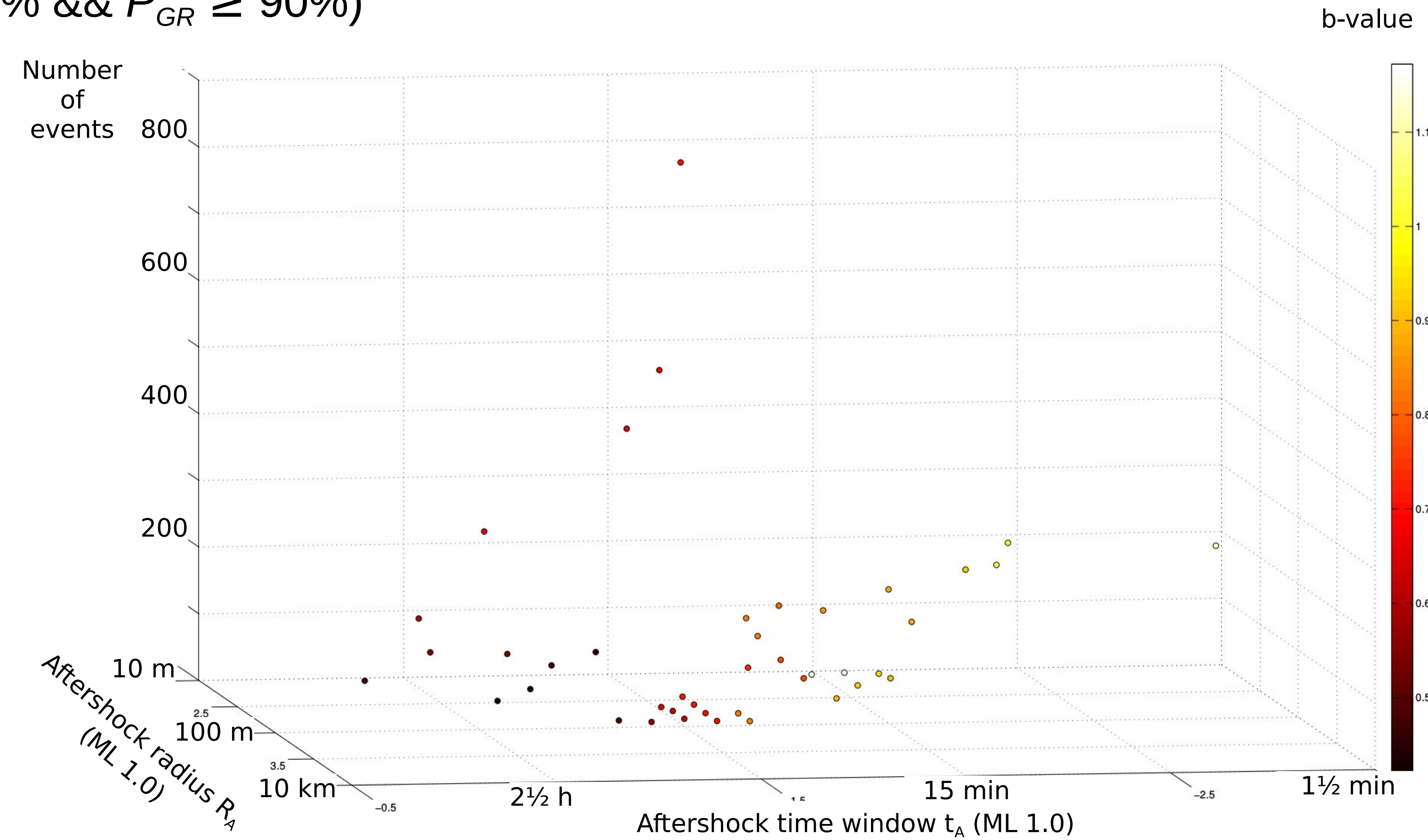
Stimulation 2005

- GR-distribution → criteria dependent
  - for very high M_C (statistical effect) → no masking of small events
  - for low R_A, high t_A with low M_C



Stimulation 2005

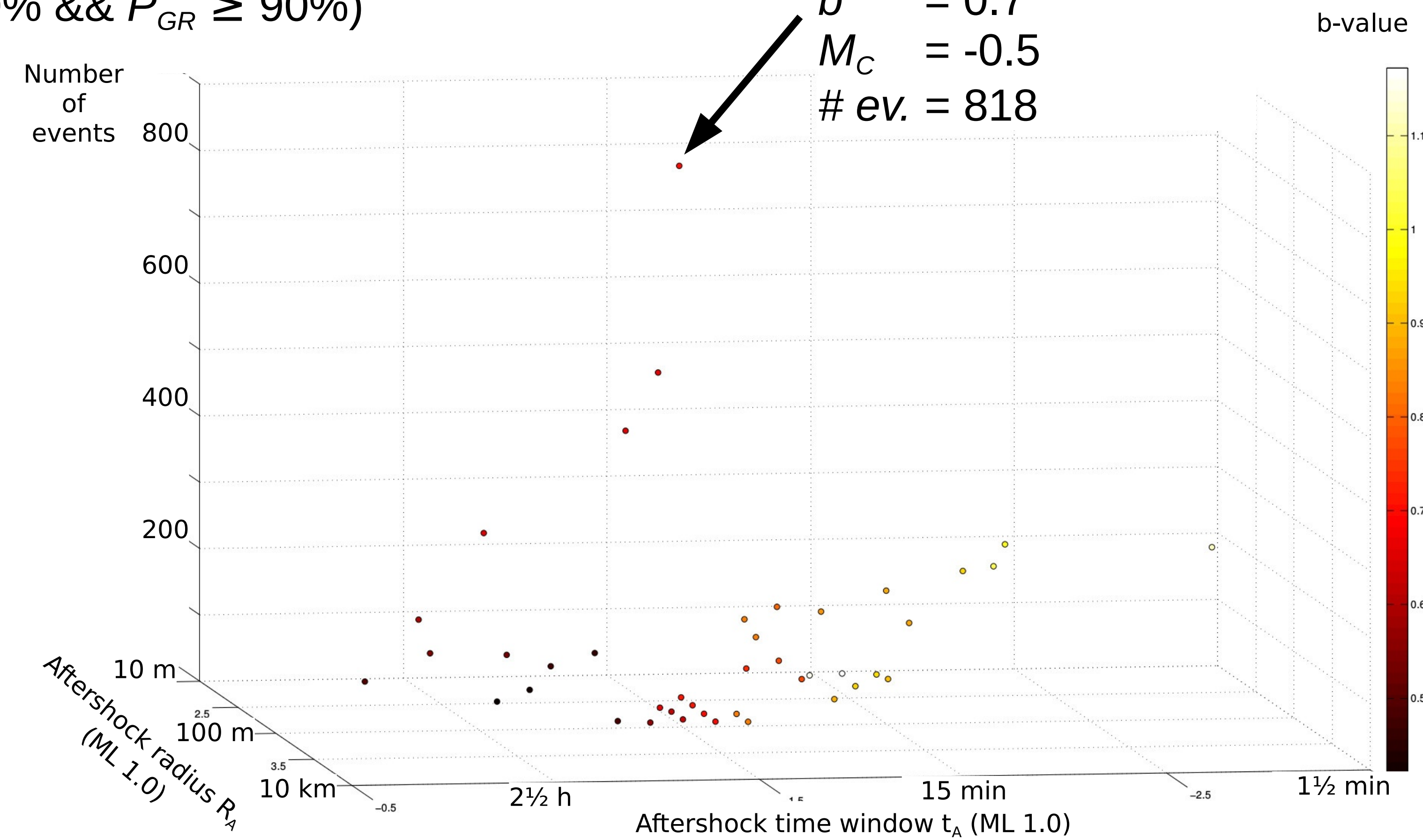
- Single realisations of GR-distributions and reasonable number of events ($P_{Pois} \geq 90\%$ && $P_{GR} \geq 90\%$)



Stimulation 2005

- Single realisations of GR-distributions and reasonable number of events ($P_{Pois} \geq 90\%$ && $P_{GR} \geq 90\%$)

R_A = *445 m* P_{Pois} = 94%
T_A = *40 min* P_{GR} = 99%
b = 0.7
M_C = -0.5
 # ev. = 818

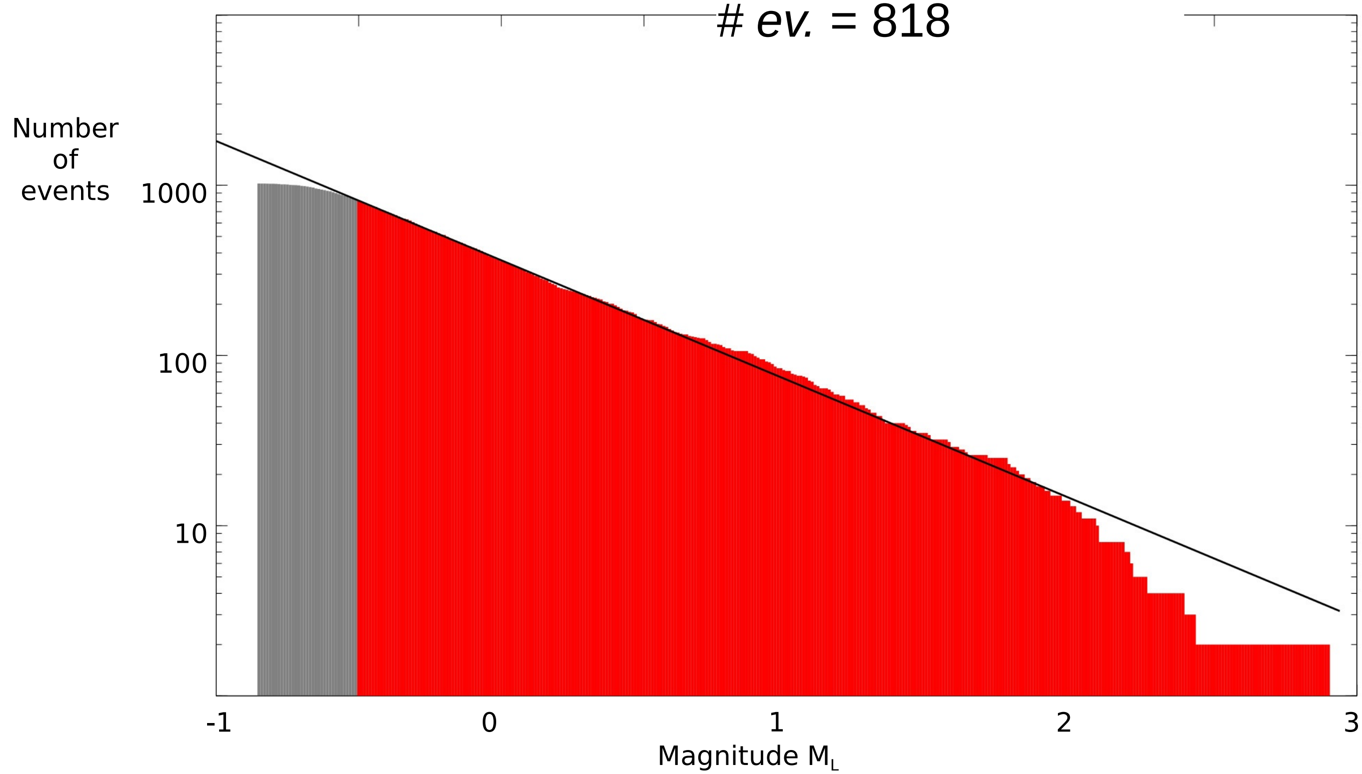


Karlsruhe Institute of Technology

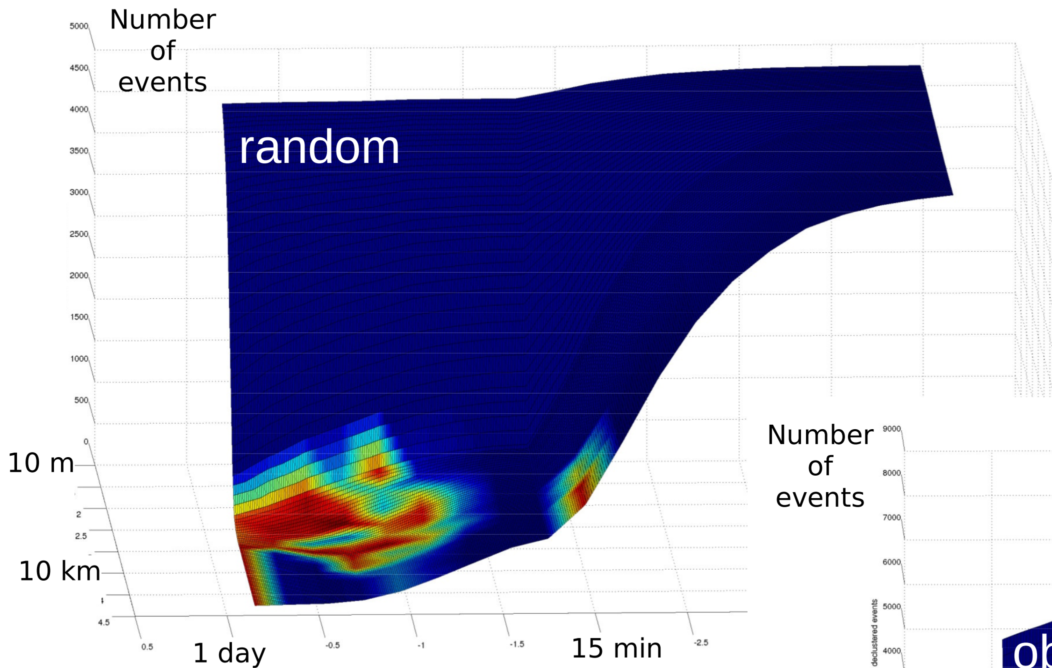
Stimulation 2005

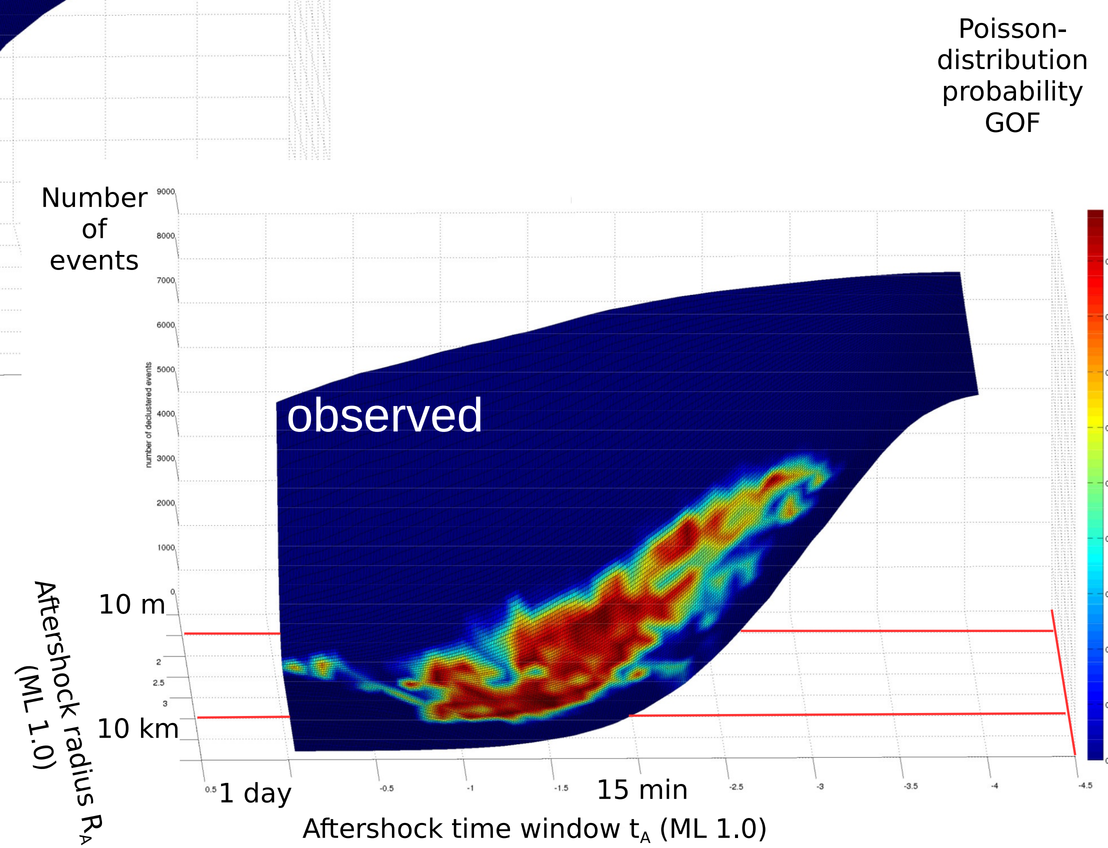
- Best subset with Poisson- & GR-behaviour
- Declustered to 12% of original number

R_A = 445 m P_{Pois} = 94%
T_A = 40 min P_{GR} = 99%
b = 0.7
M_C = -0.5
ev. = 818



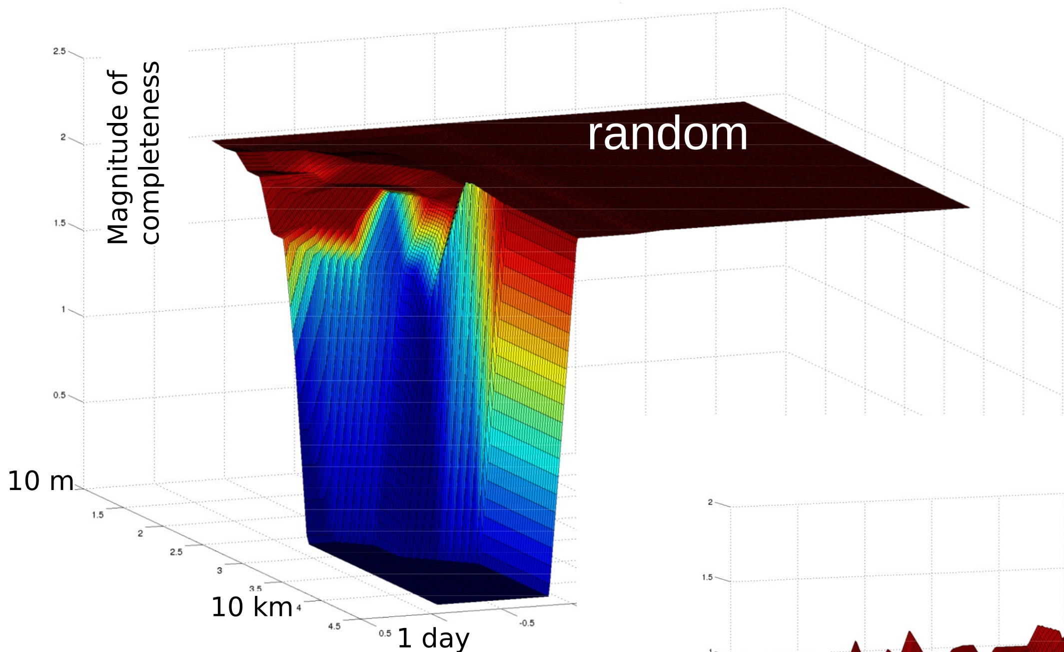
Random vs. observed data

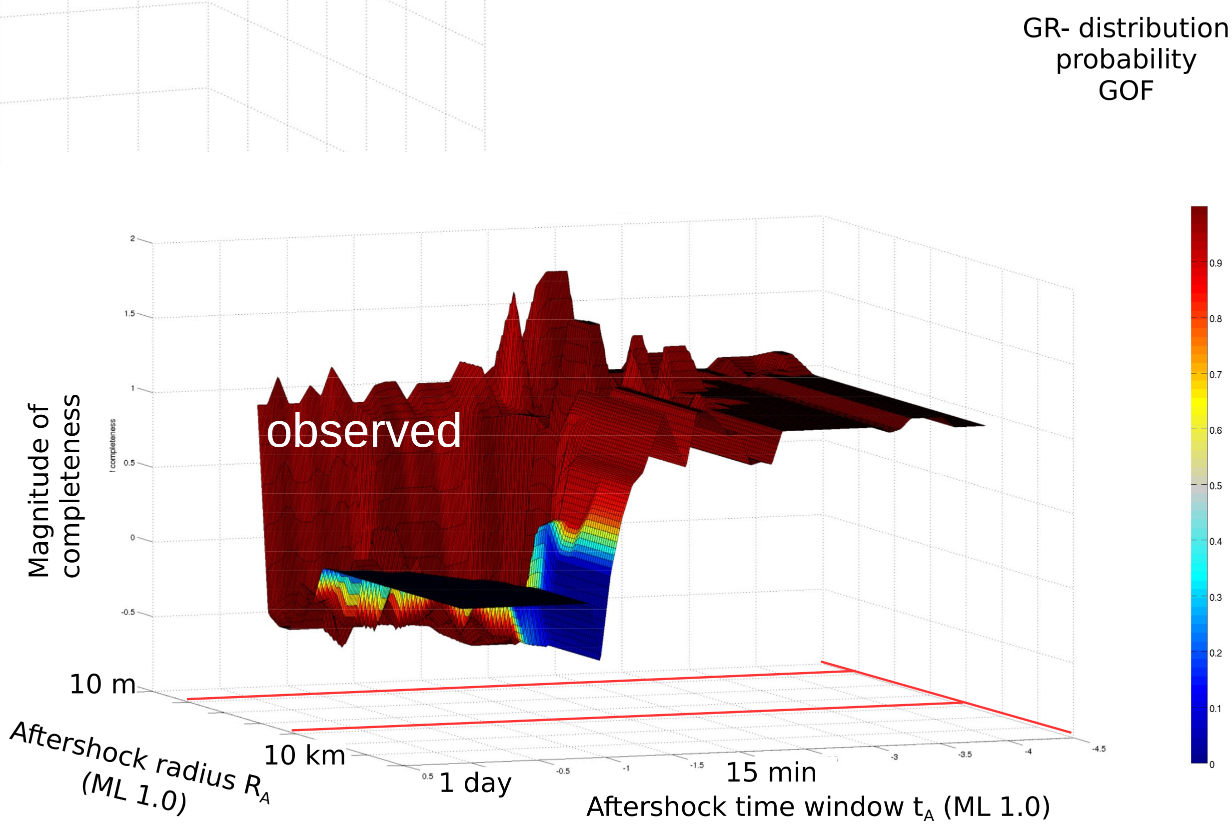




- Non-Poisson-distribution (uniform)
  - Refusal of most events
  - high t_A *(hardly time dependent)*

Random vs. observed data





- Non-GR-distribution (polynomal)
  - Refusal of most events
  - high M_C

Conclusions

- Observed data
  - Poissonian ✔
    Aftershock behaviour apparent
  - Gutenberg-Richter (✔)
    Single realisations of declustering, high refusal rate

- Uniform random data
  - Poissonian ✘
  - Gutenberg-Richter ✘
  - Refusal of most events

- Outlook
  - Further synthetic datasets (positive/false)
  - Time-/space-dependance
  - Influence of goodness-of-fit calculation

Conclusions

- Observed data
  - Poissonian ✔
    Aftershock behaviour apparent
  - Gutenberg-Richter (✔)
    Single realisations of declustering, high refusal rate
- Uniform random data
  - Poissonian ✘
  - Gutenberg-Richter ✘
  - Refusal of most events
- Outlook
  - Further synthetic datasets (positive/false)
  - Time-/space-dependance
  - Influence of goodness-of-fit calculation

Thank you

mindflash.com