Quasidynamic simulations of long deformation histories on a heterogeneous fault

Universität Potsdam

USC

Gert Zöller
Yehuda Ben-Zion
Sebastian Hainzl
Mathias Holschneider

KITP, UC Santa Barbara, October 11, 2005

Introduction:

- Use conceptual fault model to ...

  ... simulate long deformation histories (~1000 years)

- Goal:

  tune models towards real fault systems
  (e.g. Parkfield)

Study ...

- *Frequency-size distributions*
- *Mainshock occurrence*
- *Aftershocks and foreshocks*
- *Accelerating moment release*
- *Rupture histories*
- ..

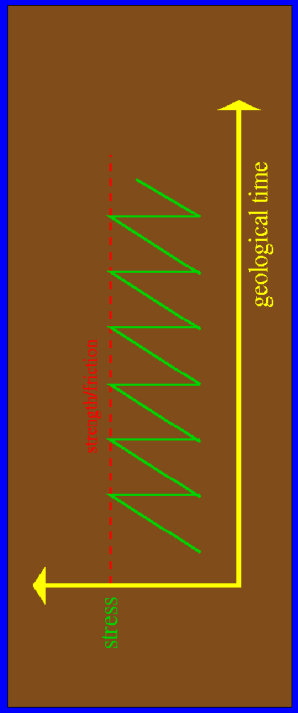
... as a function of ..

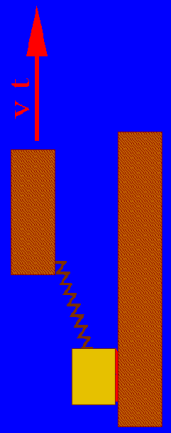
- *Friction*
- *Heterogeneities*
- ..

(Tuning parameters .. friction or roughness parameters)

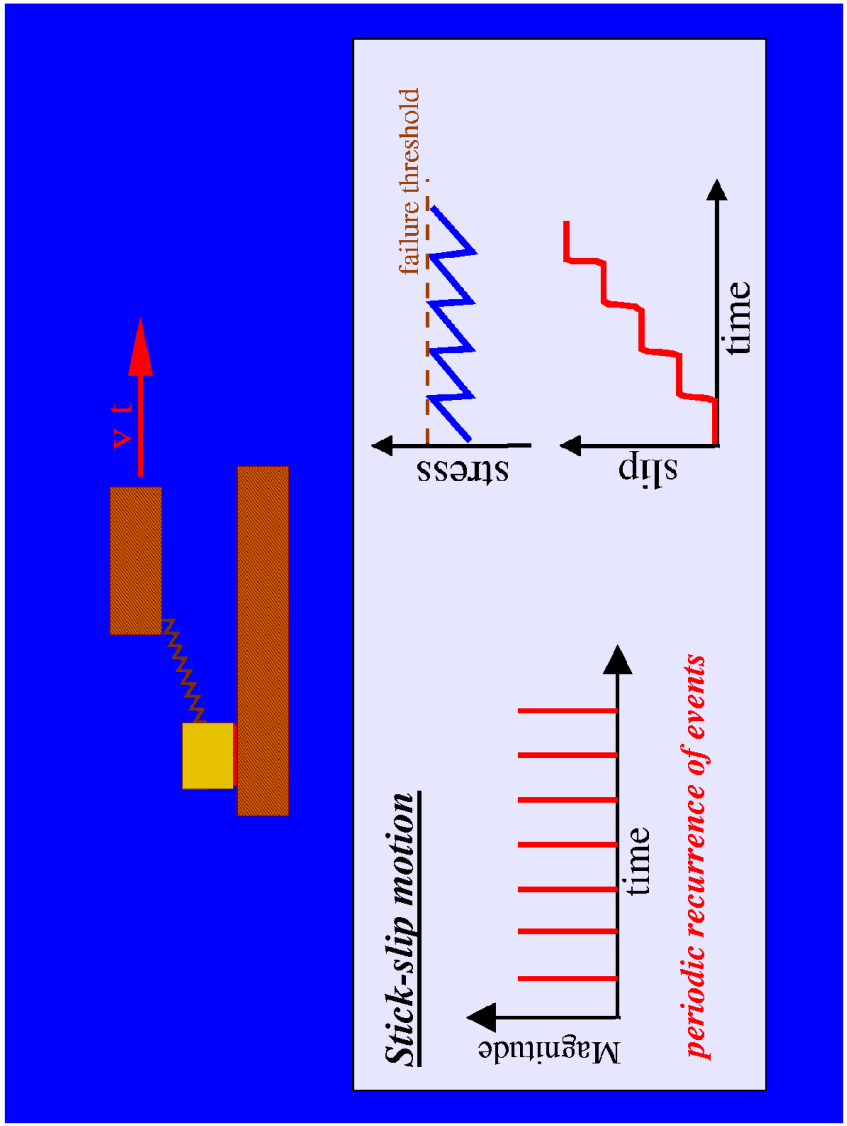
The Model

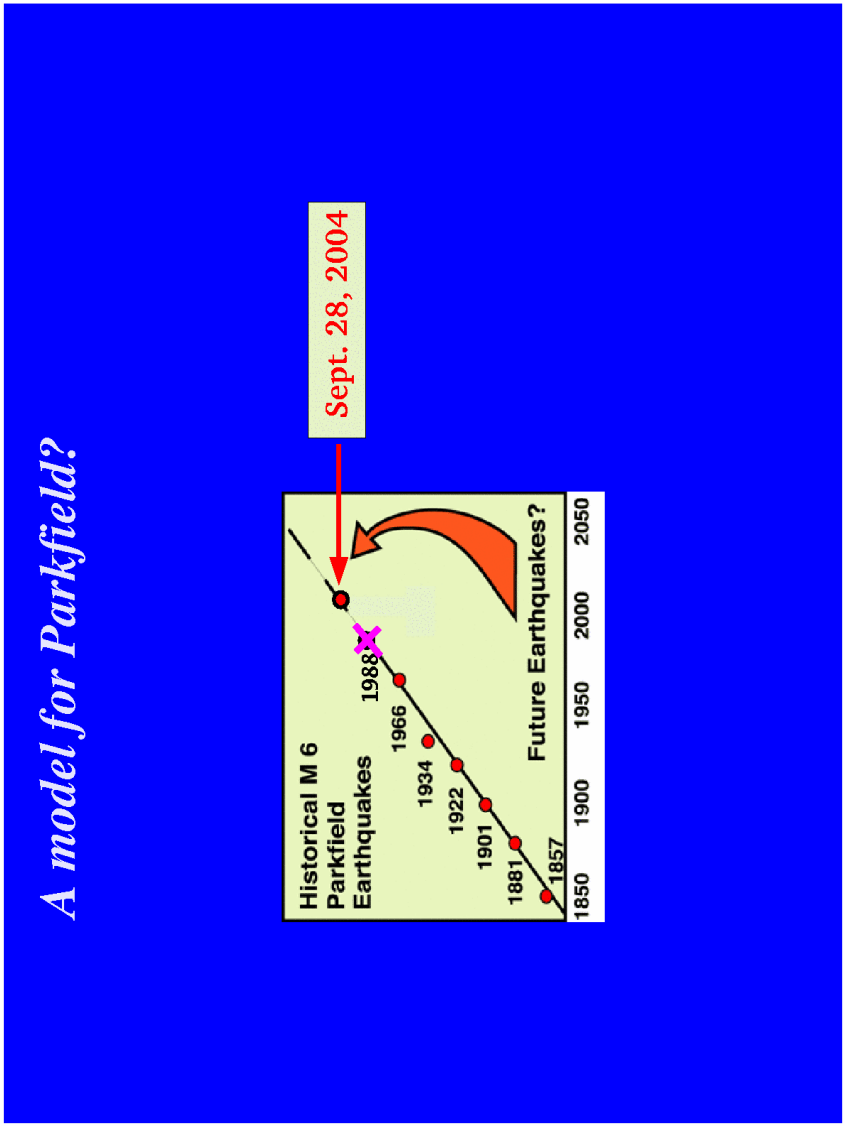
Stress / Strength → *Threshold dynamics*





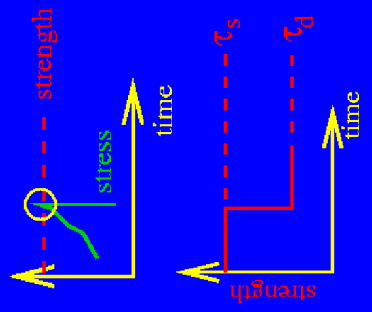
$$m\ddot{x} = K(vt - x) - R(\dot{x})$$


V t
Stick-slip motion
Magnitude
time
periodic recurrence of events
stress
failure threshold
slip
time


A model for Parkfield?
Sept. 28, 2004
Historical M 6
Parkfield
Earthquakes
1857
1881
1901
1922
1934
1966
1988
Future Earthquakes?
1850
1900
1950
2000
2050

Mechanisms

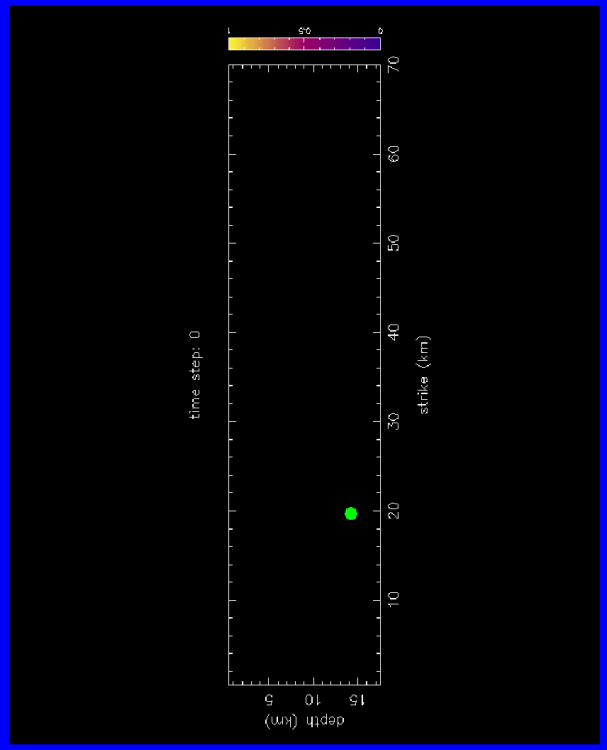
- *Plate motion: $\dot{u}$ constant (cells independent)*
- *Aseismic creep: $\dot{u} \sim$ (cells coupled!)*
  (lab experiments, satellite measurements)
- *Earthquake initiation:*



"static-kinetic friction"

Propagation of stress during an earthquake

with constant shear-wave velocity



stress field
(normalized)

Hypocenter

- *Earthquake catalogs (inter-event time scale):*
  - *earthquake time*
  - *hypocenter*
  - *earthquake size ...*

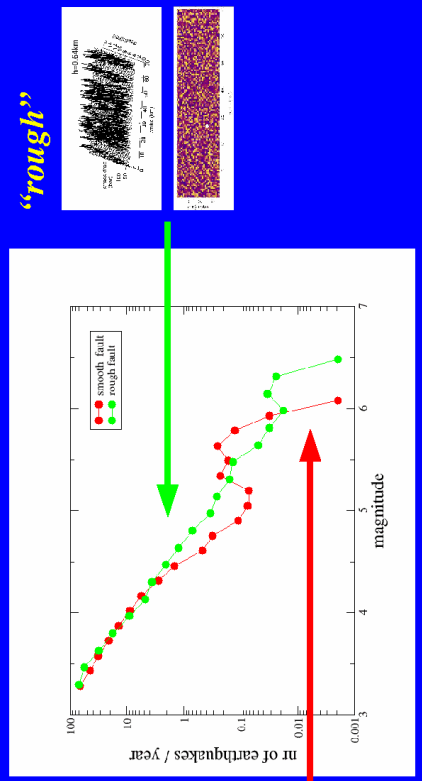
seismic moment/potency	magnitude	rupture area
$m_0 \propto \int \Delta u \, dA$	$M \propto \log m_0$	$\int dA$

- *Rupture histories (intra-event time scale):*

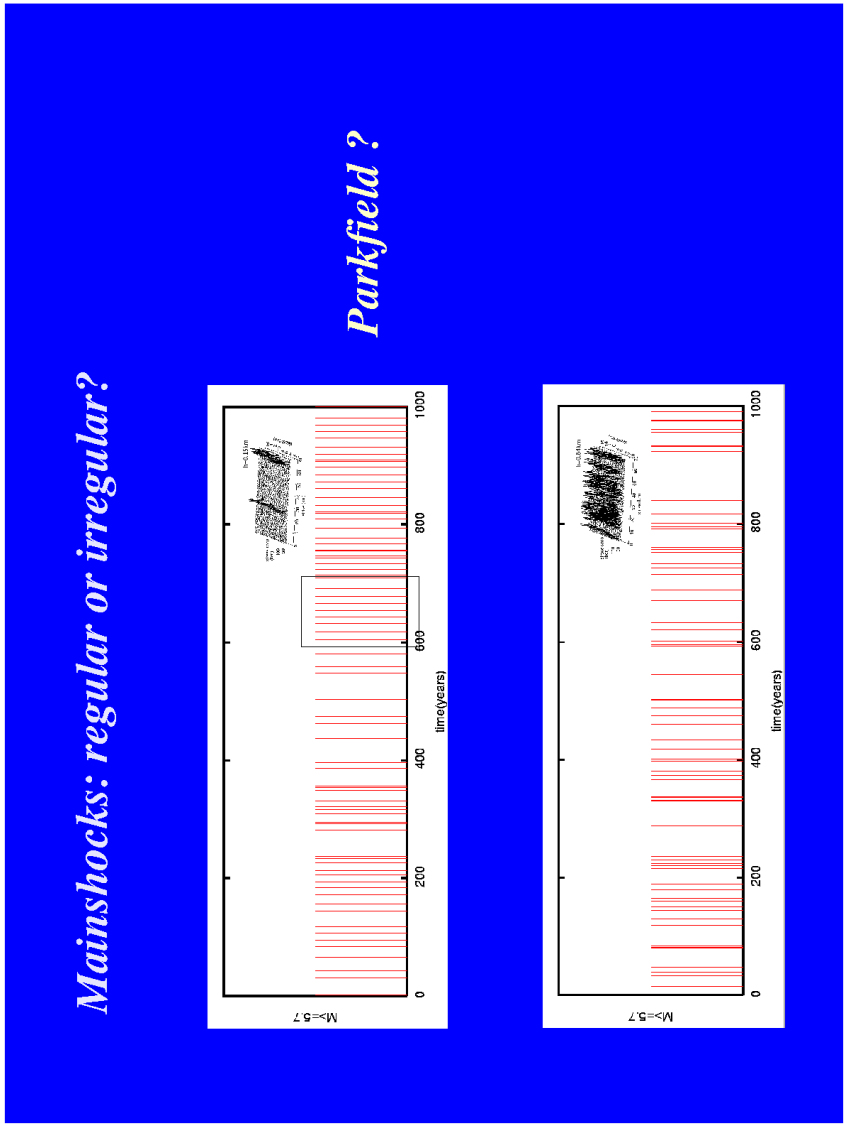
slip	stress
$\Delta u(x, z; t)$	$\Delta \tau(x, z; t)$

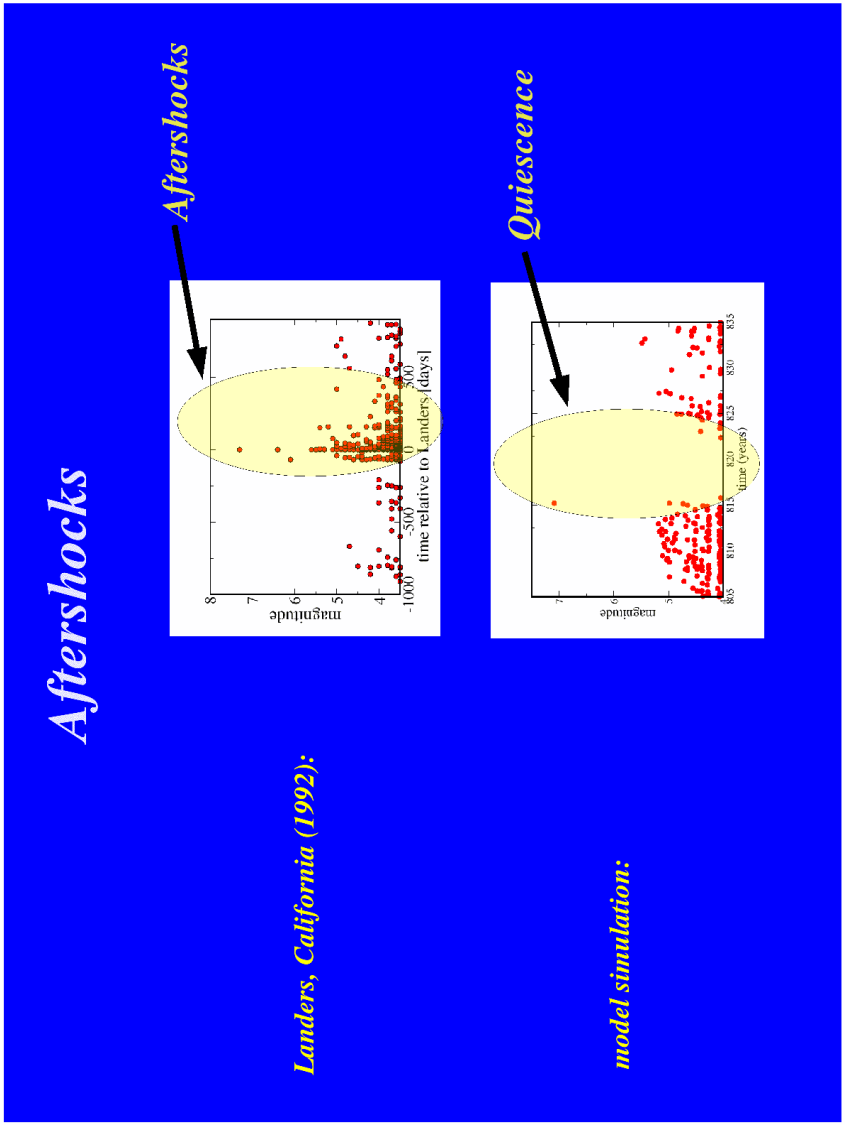
Frequency-size distribution

... as a function of the degree of heterogeneity on the fault
(e.g. in terms of the stress drop Δ)



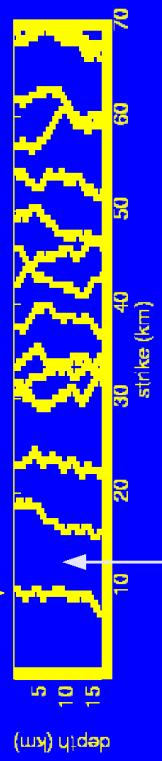
Zöller, Holschneider & Ben-Zion: Pure Appl. Geophys, 162 (2005)
Zöller, Holschneider & Ben-Zion: Pure Appl. Geophys, 161 (2004)


Mainshocks: regular or irregular?
Parkfield ?
M>=5.7
time(years)
0
200
400
600
800
1000
M>=5.7
time(years)
0
200
400
600
800
1000


Aftershocks
Aftershocks
Quiescence
Landers, California (1992):
model simulation:
magnitude
time relative to Landers [days]
-1000
-500
0
500
magnitude
time (years)
805
810
815
820
825
830
835

Seismic and aseismic zones

creeping barriers V_{cr}

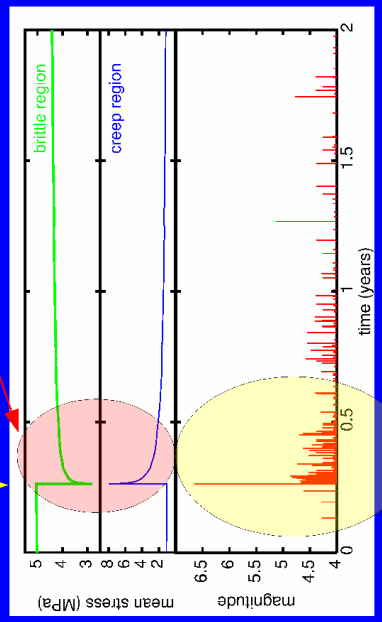


seismic patches V_{cr}

Aftershocks and afterslip

Mainshock

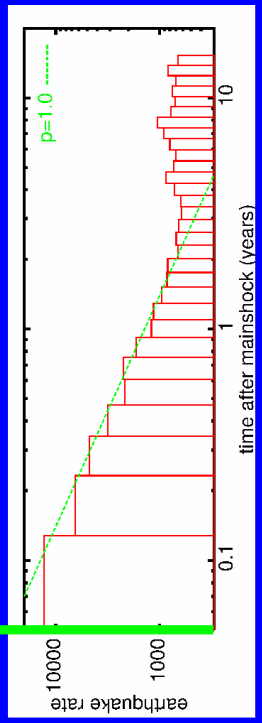
"Afterslip" (GPS/InSAR)

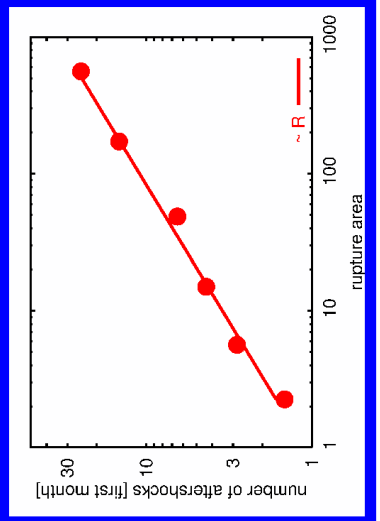


Aftershocks!

200.000 earthquakes stacked (~5000 years)

mainshock

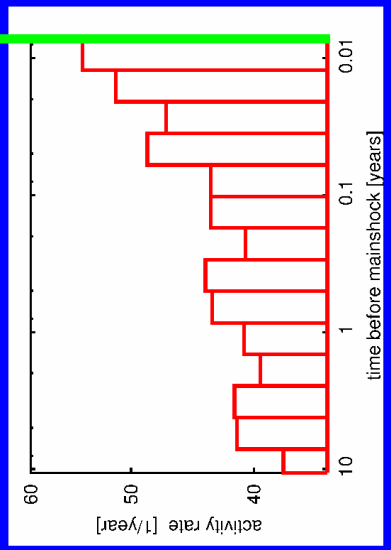




Omori: $\dot{n}(t) \propto t^{-p}$

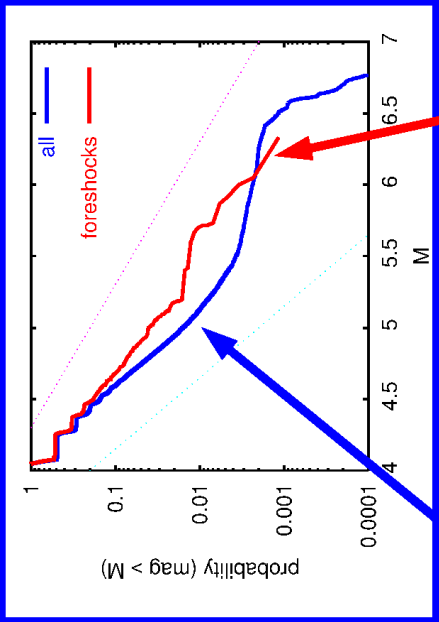
p depends only on V_{cr}/v_{cr}

Stacked earthquake rate *before* mainshock



Zöller, Hainzl, Ben-Zion & Holschneider: Tectonophysics, in press (2005)
Zöller, Hainzl, Holschneider & Ben-Zion: Geophys. Res. Lett. 32 (2005)
Hainzl, Zöller & Kurths: J. Geophys. Res. 104 (1999)

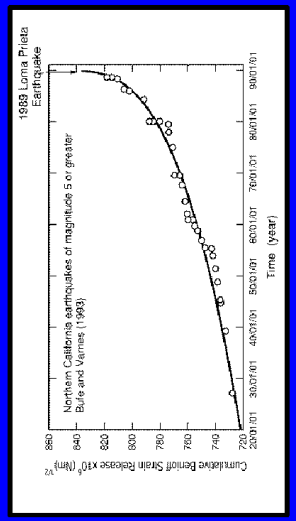
Frequency-size distribution (cumulative)



characteristic EQ distribution ("smooth")

Gutenberg-Richter-distribution ("scale-free")

Accelerating seismic moment release



Bufe & Varnes, 1993

$$\sum E^{1/2} \sim (t_c - t)^m$$

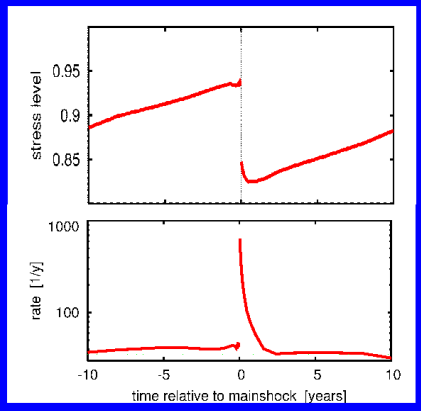
cumulative Benioff strain

mainshock time

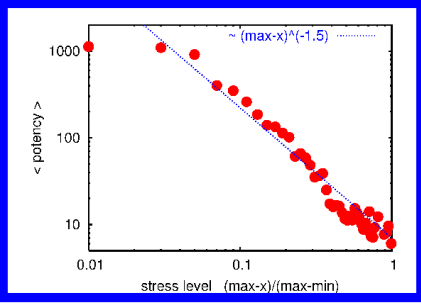
Accelerating seismic moment release ("Benioff strain")

Stress:

EQ rate:



Potency as a function of stresslevel:



$$\sum E^{1/2} \sim (t_c - t)^{m}$$

Exponent m:

model: ***m=0.25***

observational:

Bufe & Varnes, 1993 (Loma Prieta): m=0.3

Bowman et al., 1998 (California): m=0.18, ..., 0.55

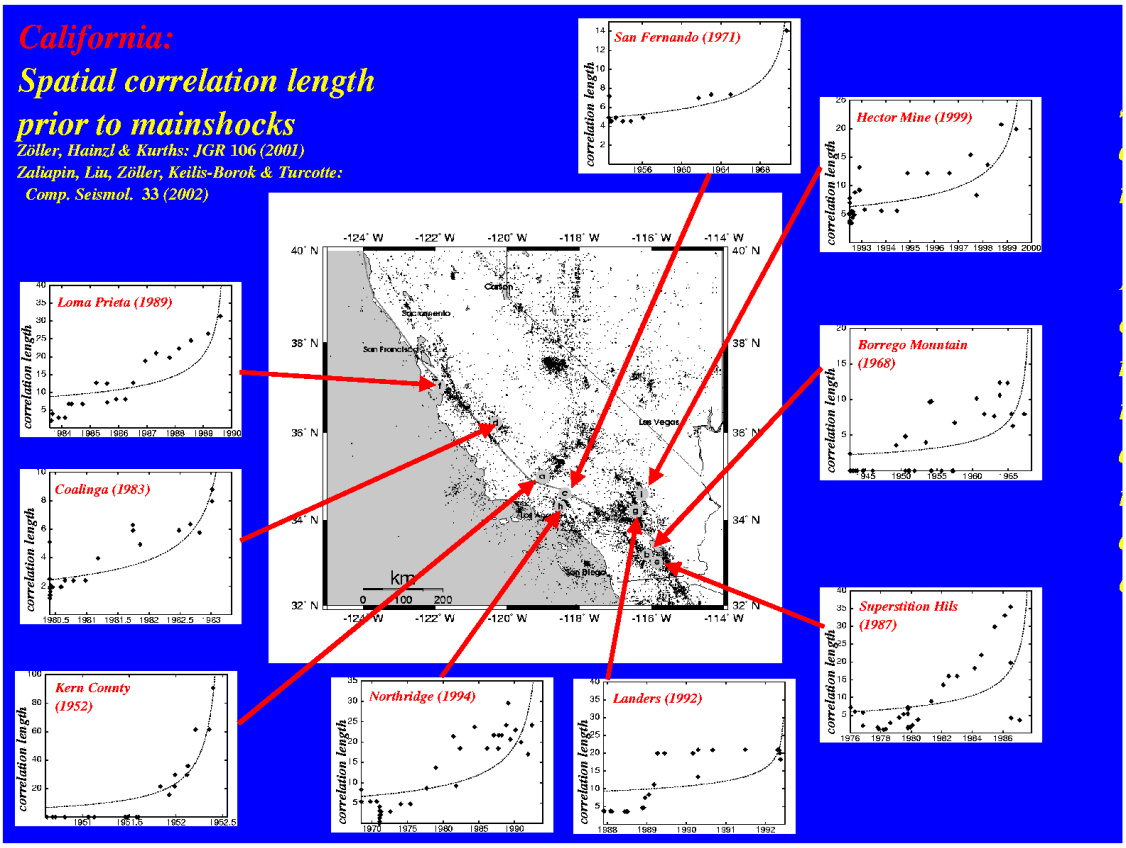
theoretical:

Rundle et al., 2000: m=0.25

Ben-Zion & Lyakhovsky, 2003: m=0.3

California:
Spatial correlation length prior to mainshocks

Zöller, Hainzl & Kurths: JGR 106 (2001)
Zaliapin, Liu, Zöller, Keilis-Borok & Turcotte: Comp. Seismol. 33 (2002)



Summary

- *The model produces ...*

  ... realistic frequency-size distributions
  ... realistic clustering properties

- *Long simulations unveil more characteristics of seismicity patterns.*

- *The "critical earthquake concept" is supported.*

- *Spatial heterogeneities ...*

  ... play an important role for earthquake statistics ...
  ... for the occurrence of mainshocks.
  ... (for the rupture dynamics)

Thank you very much!