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"Seventh Workshop on Non-Linear Dynamics and Earthquake Prediction"

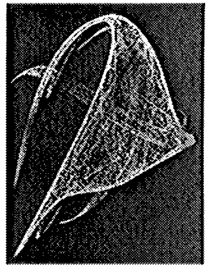
29 September - 11 October 2003

EARTHQUAKES - complex or complicted

Christian Goltz

Geophysics, CAU Kiel & SFB 574
Kiel, Germany

strada costiera, 11 - 34014 trieste italy - tel. +39 040 2240111 fax +39 040 224163 - sci_info@ictp.trieste.it - www.ictp.trieste.it



Earthquakes -

complex or complicated?

Christian Goltz, Geophysics, CAU Kiel & SFB 574

goltz@geophysik.uni-kiel.de

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Trieste, 01.10.2003

Contents

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Complex vs. Complicated

Complex – consisting of many parts; Complicated – difficult

Informatics:

Descriptional CX (~ Kolmogorov): length of program? (Pattern: size after compression?);

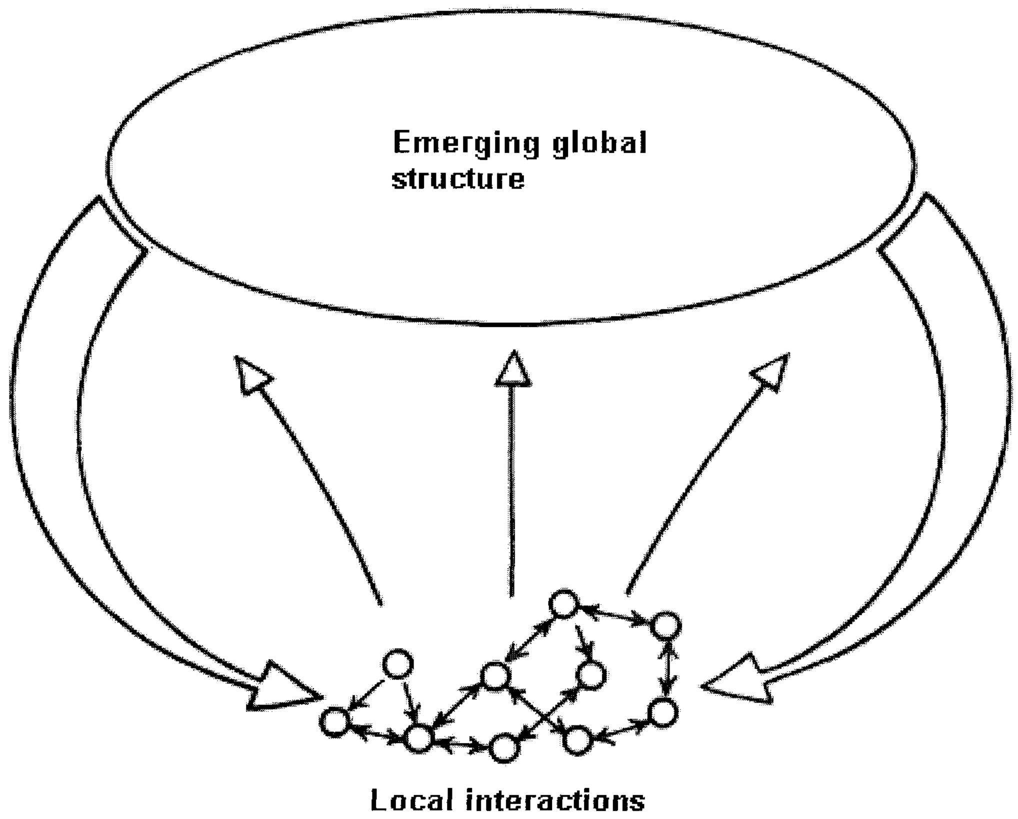
Computational CX: resources needed (time, memory)

Here:

Working definition, amounts chiefly to critical systems.

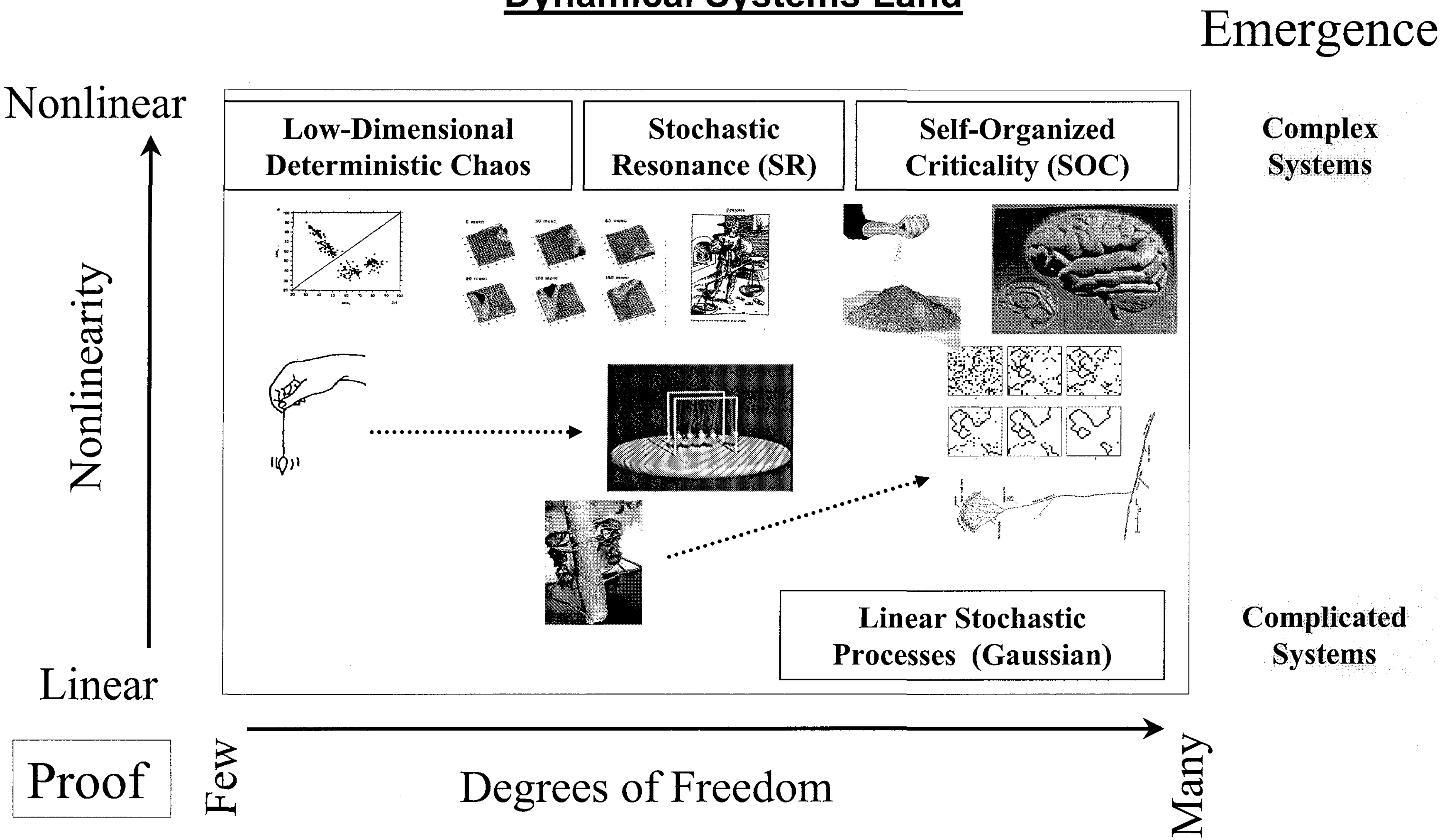
Generally: If a system is complex and, if so, to what degree, depends on the chosen description.

Emergence: Local non-linear interaction of many parts leads to unpredictable global order



Lewin, 1992, Complexity. Life at the Edge of Chaos (after Chris Langton)

Dynamical Systems Land



Chialvo, 2003, unpublished

Earthquakes: Observations

No reproducible success in prediction since > 100 a.

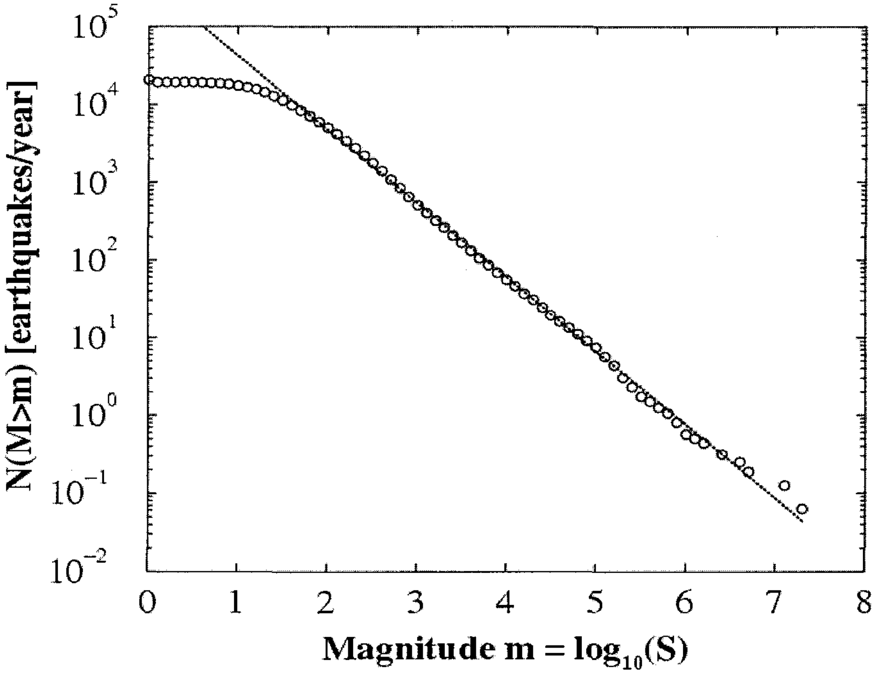
Instead: Observation of power laws, long range triggering, induced seismicity, …

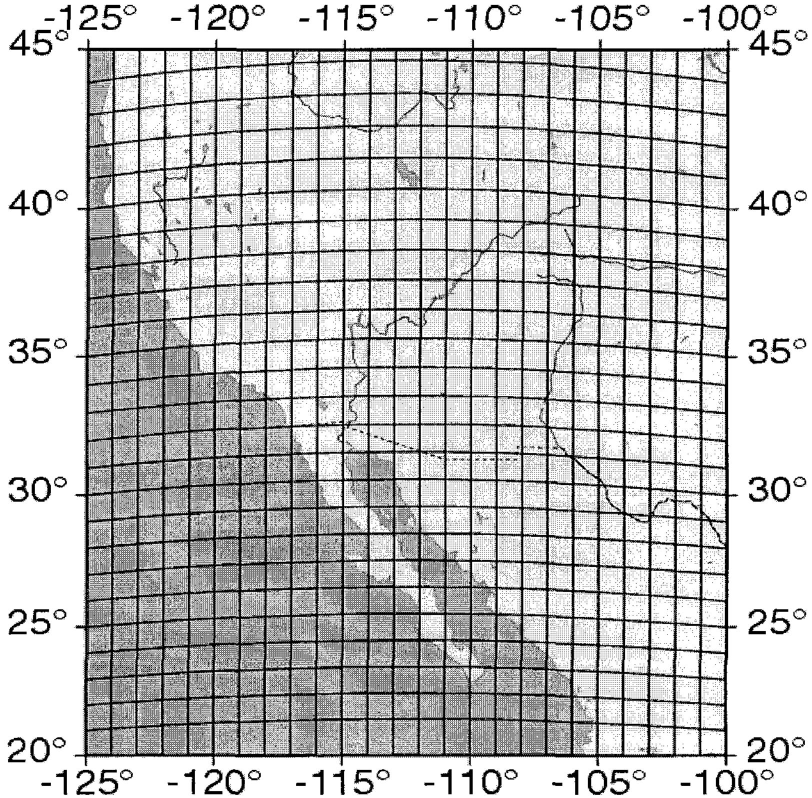
Laboratory experiments and simulations of single faults resp. blocks do not produce realistic results.

e.g. California

$$\log_{10} N(M > m) \propto -bm$$

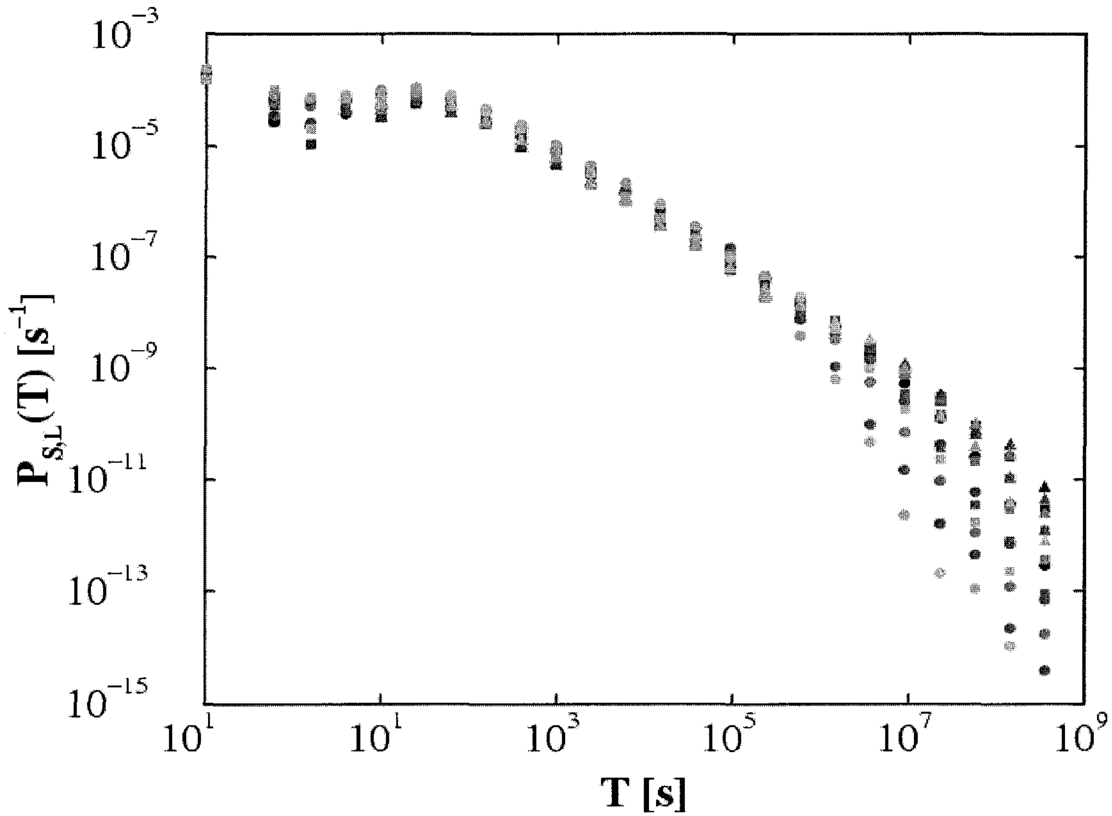
$$N(S > s) \propto s^{-b}$$





Christensen et al, 2002, PNAS

$N(T) \propto T^{-\alpha}$ resp. 1/f-noise



Christensen et al, 2002, PNAS

PLUS:

Faults and spatial distributions of earthquakes are fractal.

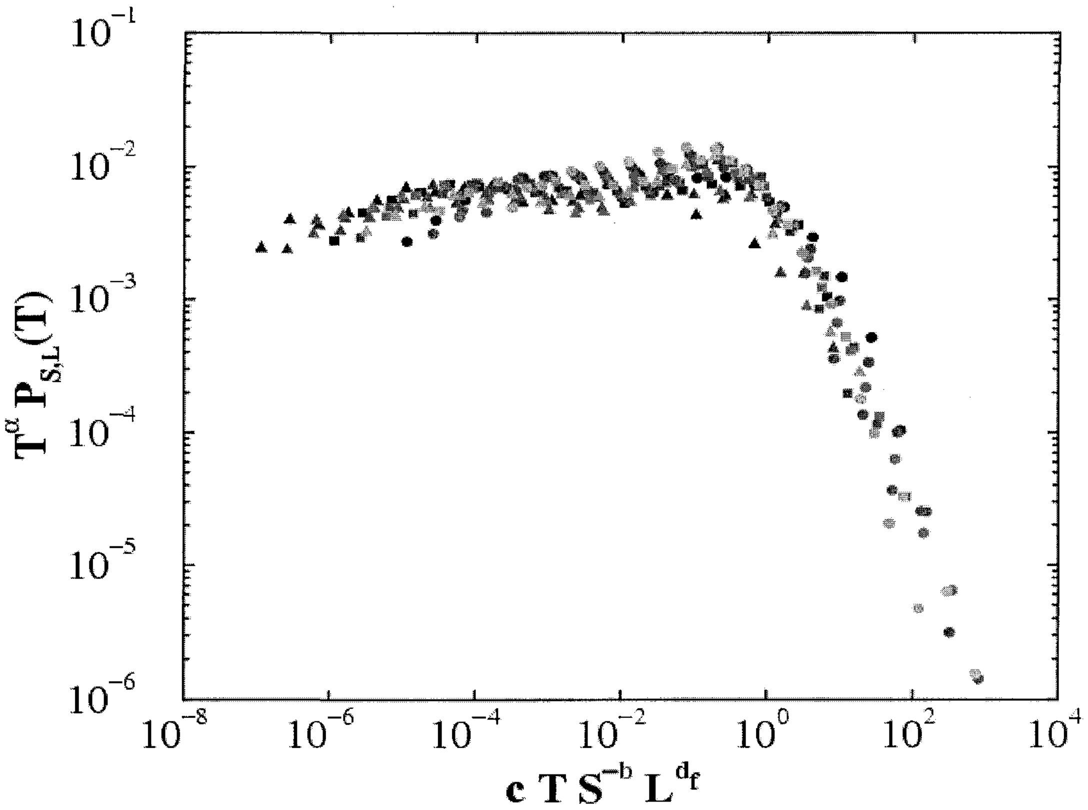
Spatio-temporally coupled scale-invariant system

→

Can these observations be combined?

$$P_{S,L}(T) \propto T^{-\alpha} f(T L^{d_f} S^{-b})$$

Fit: $\alpha \sim 1$, $b \sim 1$, $d_f \sim 1.2$!



Christensen et al, 2002, PNAS

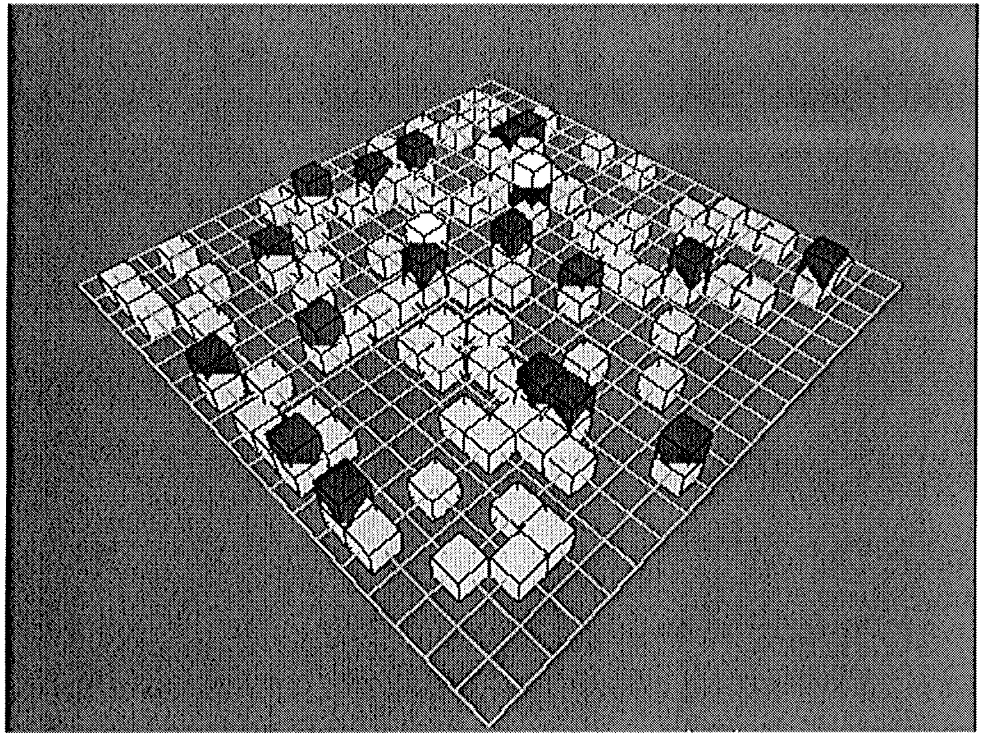
"All eqs are aftershocks."

Earthquakes are a self-organised critical system.

Looking at individual events is useless for understanding the whole system

→ complex system.

Earthquakes: Models



The sandpile (Bak et al)

Methods

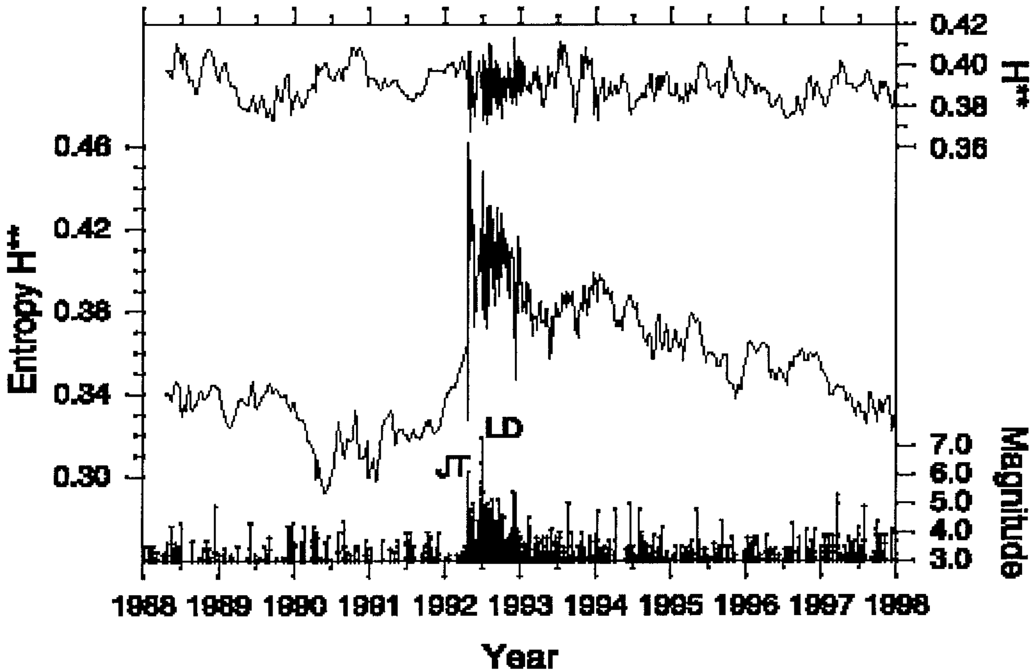
Methods that are suitable to describe and ultimately predict the complex spatio-temporal evolution of seismicity.

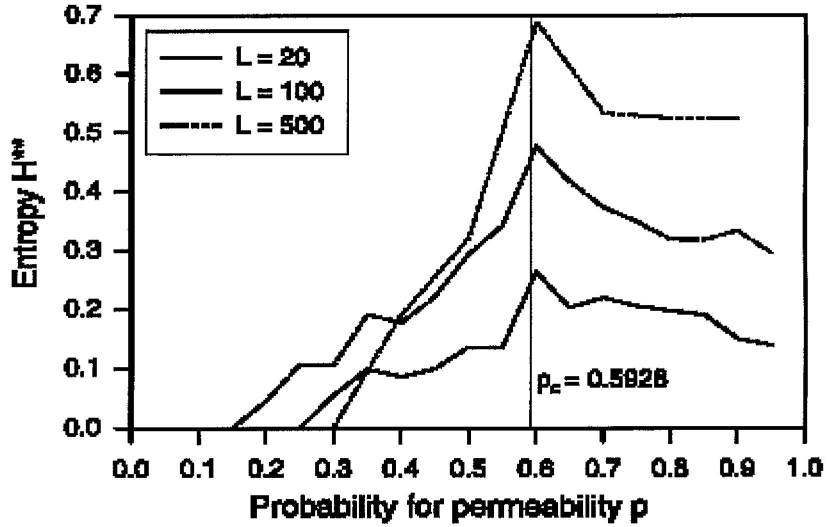
From local to global approaches.

Local: Configurational Entropy

$$I_i = \ln \frac{1}{p_i}.$$

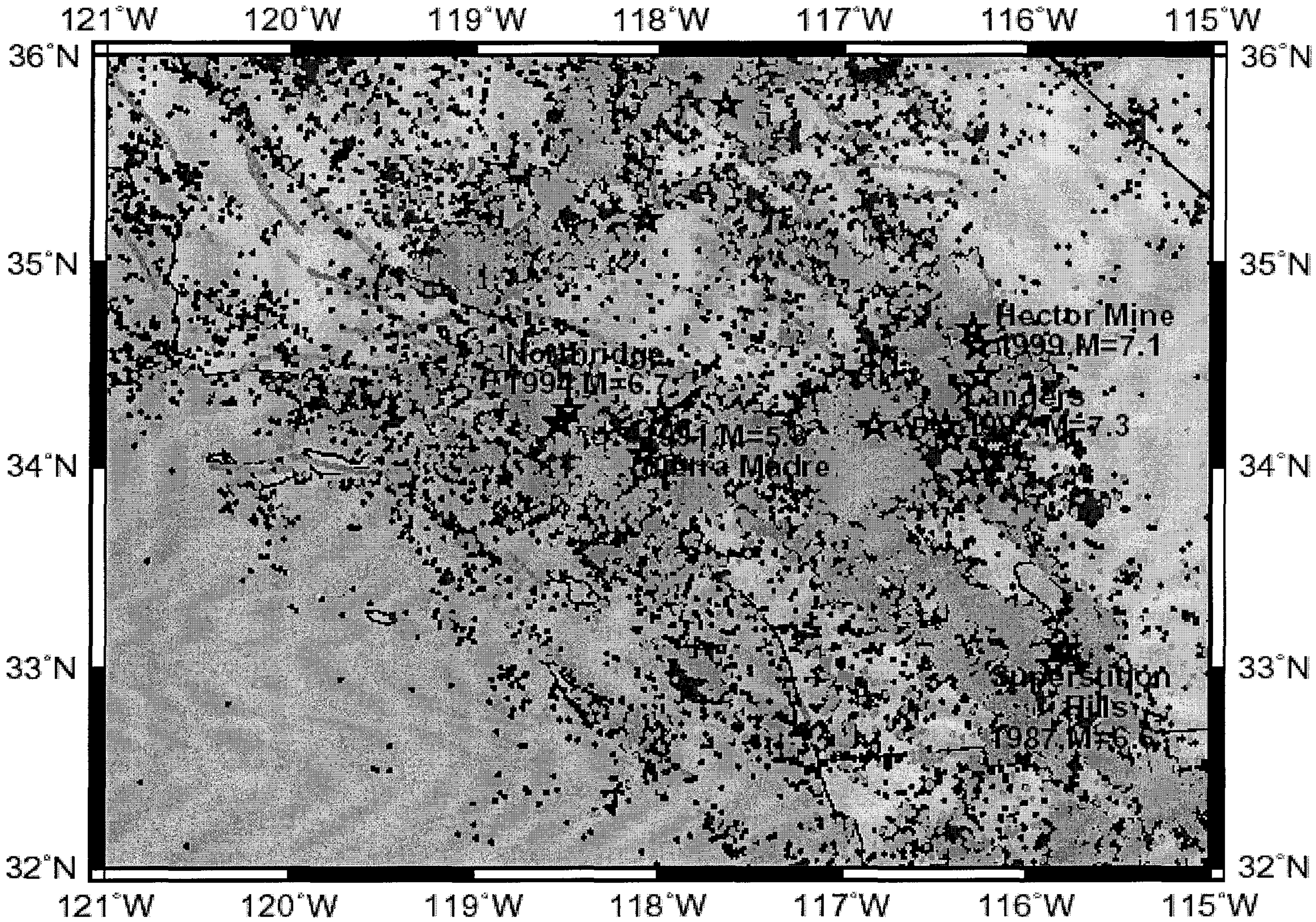
$$H = \sum_{i=1}^{n} p_i I_i = -\sum_{i=1}^{n} p_i \ln p_i.$$

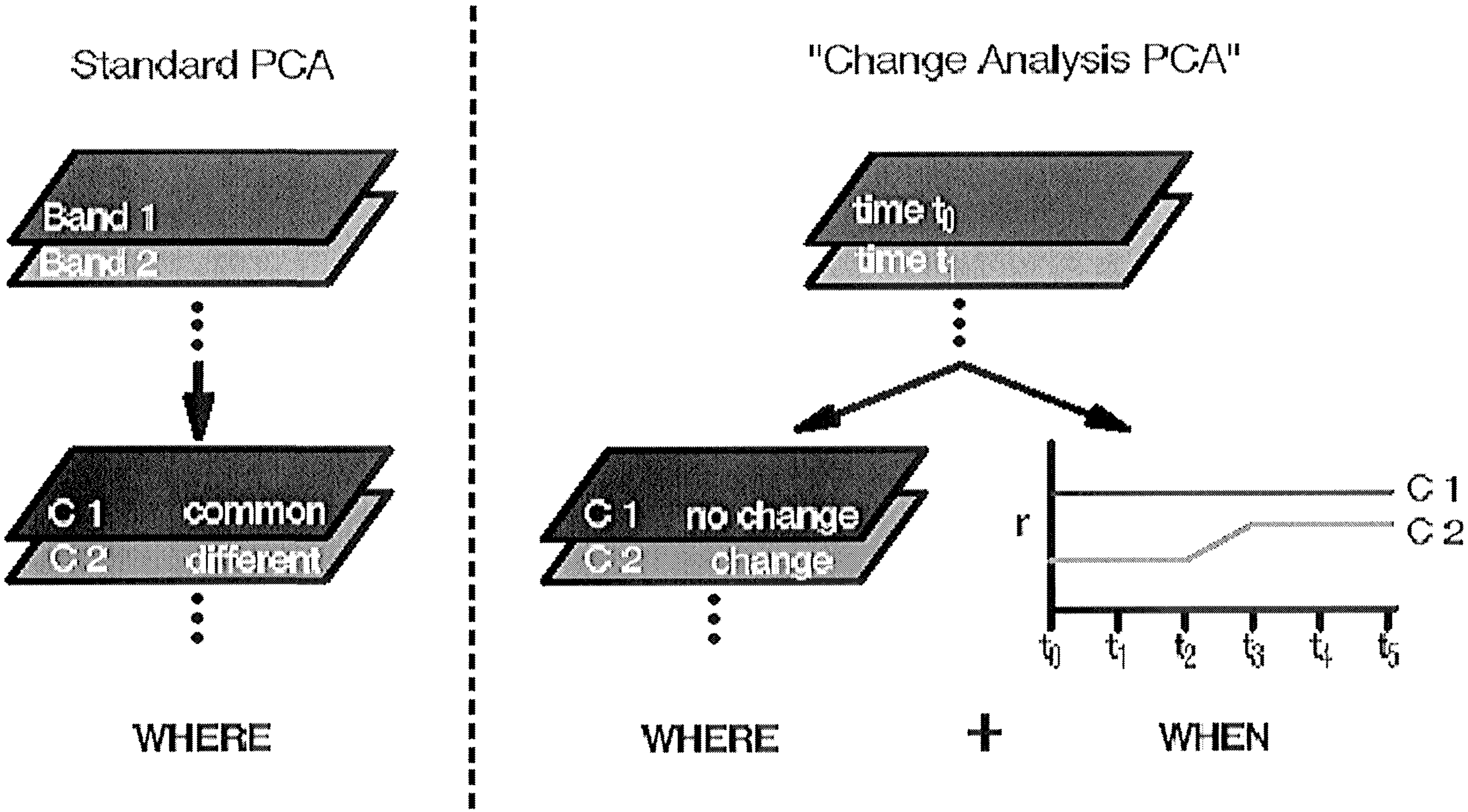




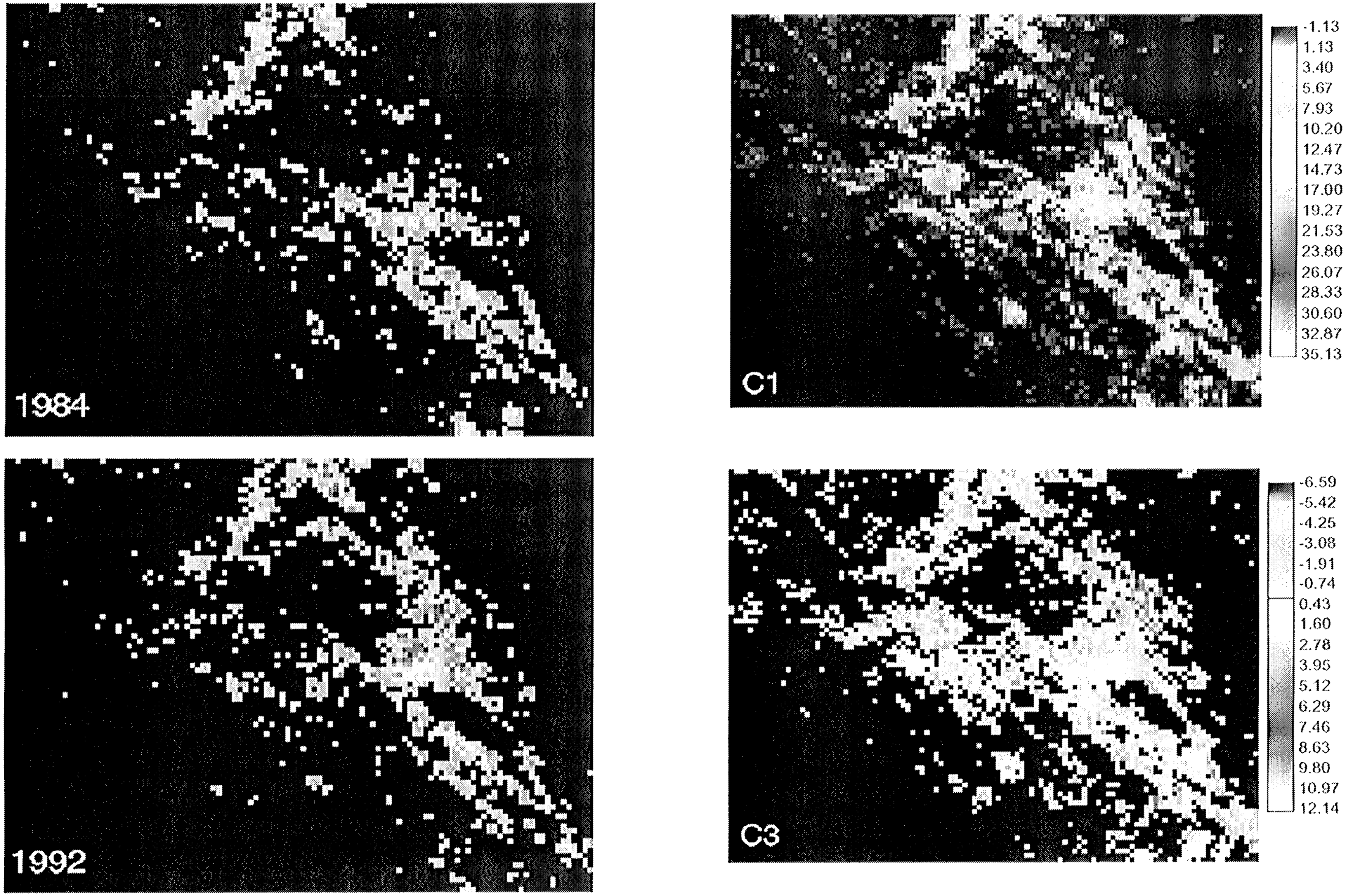
Goltz & Böse, 2002, GRL

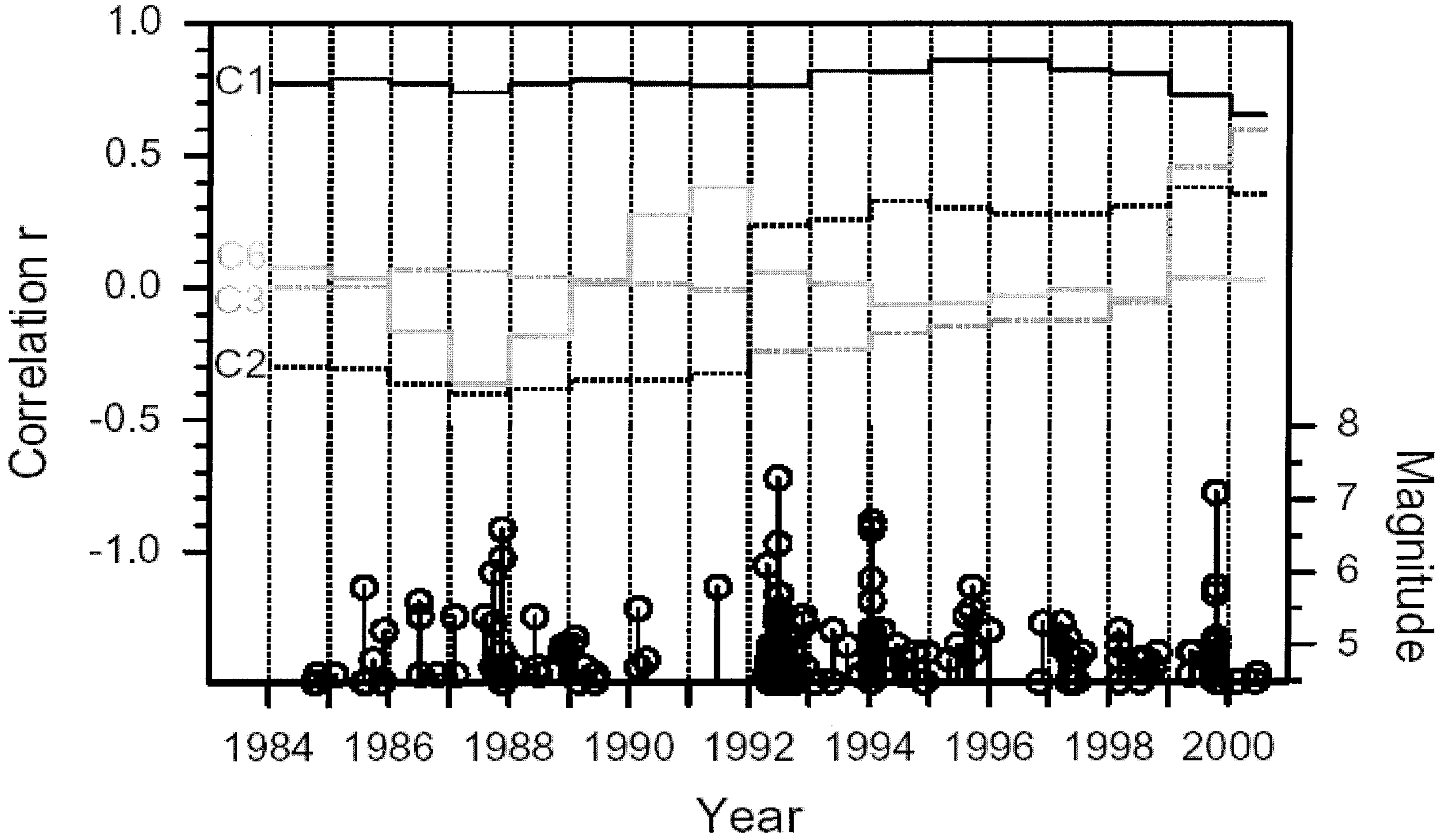
Global: Spatio-temporal Principal Components Analysis





Goltz, 2001, Nat. Haz. Earth Syst. Sci.


1984
1992
C1
-1.13
1.13
3.40
5.67
7.93
10.20
12.47
14.73
17.00
19.27
21.53
23.80
26.07
28.33
30.60
32.87
35.13
C3
-6.59
-5.42
-4.25
-3.08
-1.91
-0.74
0.43
1.60
2.78
3.95
5.12
6.29
7.46
8.63
9.80
10.97
12.14



Goltz, 2001, Nat. Haz. Earth Syst. Sci.

Global: Phase dynamics (PDPC)

Seismic activity rate

$$S(\boldsymbol{x}, t_b, t) \equiv \frac{1}{(t - t_b)} \int_{t_b}^{t} n(\boldsymbol{x}_i, t)\, \mathrm{d}t.$$

Change in probability of an earthquake

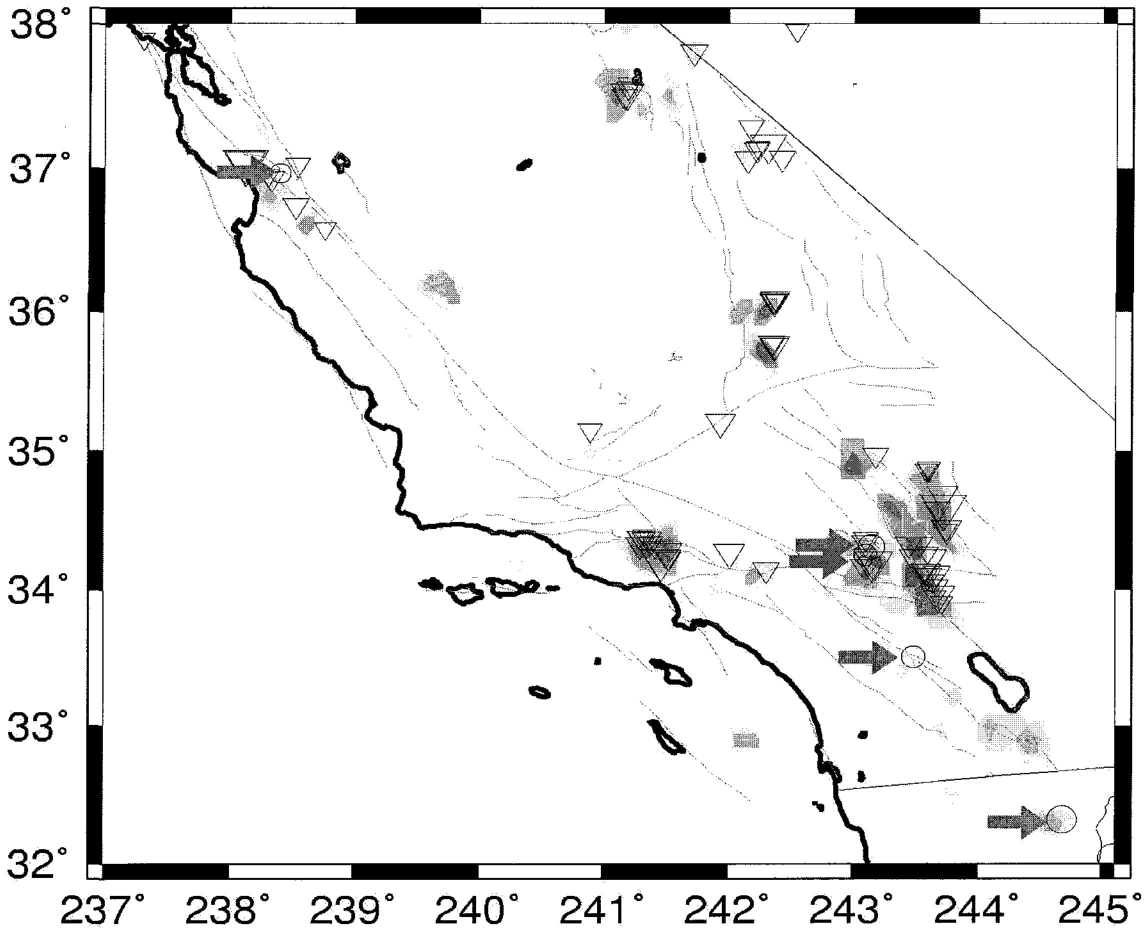
$$\Delta P(\boldsymbol{x}_i, t_1, t_2) \equiv [\Delta s(\boldsymbol{x}_i, t_1, t_2)]^2 - \mu_{\mathrm{B}}(t_1, t_2),$$

$$\mu_{\mathrm{B}}(t_1, t_2) \equiv \frac{1}{V} \int_V \{\Delta s(\boldsymbol{x}_i, t_1, t_2)\}^2\, \mathrm{d}\boldsymbol{x}.$$

Does it work?

Tiampo et al, 2002, PNAS

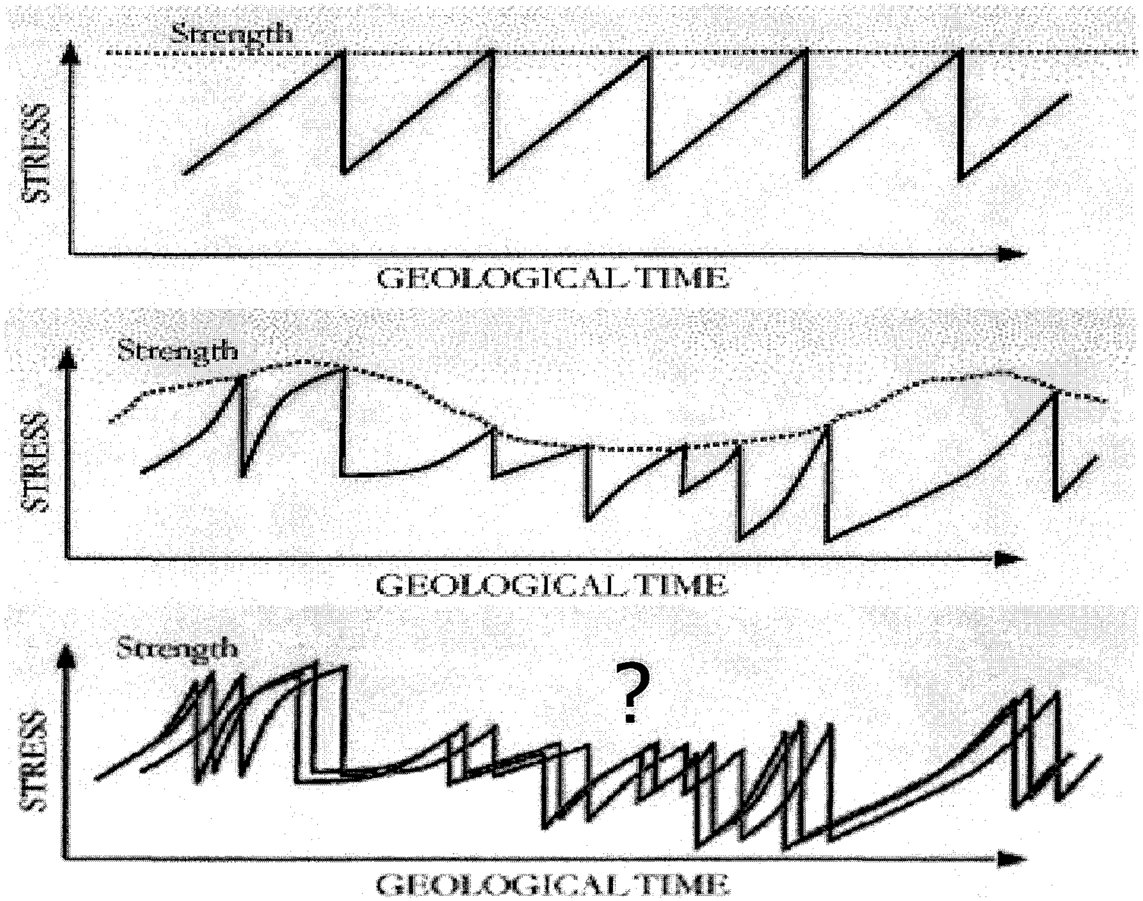
Prediction experiment: M>=5, 2001-2010!



Tiampo, 2003, pers. comm. (as of June 2003)

Conclusion & Outlook

Earthquakes are complex and complicated – Dynamical Complexity



simple

complicated

complicated + complex

after Kanamori & Brodsky, 2001, Phys. Today

Dynamic complexity prevents the classical (deterministic) prediction of individual events.

Punctiform (scalar) field measurements as well as local analysis methods are not suitable – earthquakes must be observed and analysed collectively for a given seismogenic region.

Probabilistic forecasts in the sense of time-dependent hazard seem possible then.

Advancement of global methods should allow a better specification also of time and size of a future earthquake.