Rundle Research Group

Soft Condensed Matter Applications

Market Street
San
Francisco
April 14, 1906

YouTube
Video

John B Rundle

Distinguished Professor, University of California, Davis (www.ucdavis.edu)
Chairman, Open Hazards Group (www.openhazards.com)

April 18, 1906 San Francisco Earthquake M~8

The earthquake struck at 5:12 am, PDT

Rundle Research Group

Complex Systems

- Collaborators:
  - Prof. Donald Turcotte (Geology, NAS)
  - Prof. Louise Kellogg (Geology)
  - Prof. James Crutchfield (Physics)
  - Prof. Raisa D'Souza (Eng.)
- Research Staff
  - M. Burak Yikilmaz
- Students
  - Kasey Schultz (Physics)
  - John Wilson (Physics)
  - Molly Luginbuhl (Physics)

Topics:

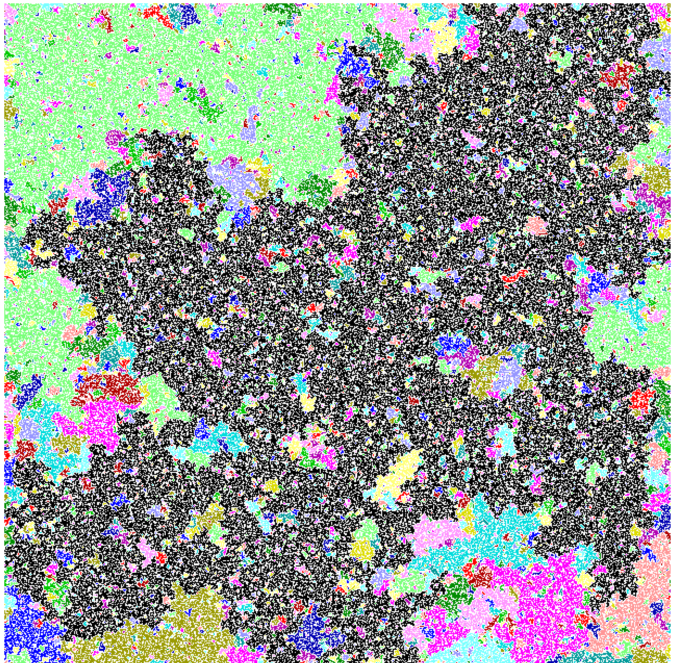
Phase Transitions
Materials Science
Earthquakes
Data Science
Econophysics (WQ 2017)
Computational Finance

Phase Transitions: Example

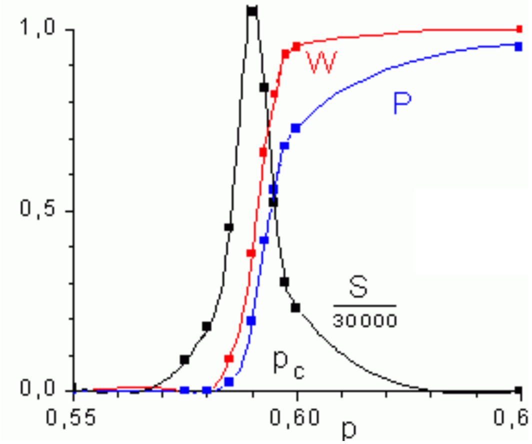
Percolation Models at the Critical (Percolation) Point

Mean field percolation occurs when the dimension d □ 6 and power laws (scale invariance) is observed. Values of scaling exponents are:

Order Parameter	□ = 1
Specific Heat	□ = 1
Susceptibility	□ = -1
Correlation Length	□ = 1/2
Cluster numbers	□ = 5/2
Surface Exponent	□ = ½



Percolation clusters at p = 0.5927 on a 640 x 640 Lattice



At the critical (percolation) point, the probability of finding a spanning cluster is W(p), with density per lattice site P(p). S(p) is the probability density function.

also:

Microscopic heat ◀

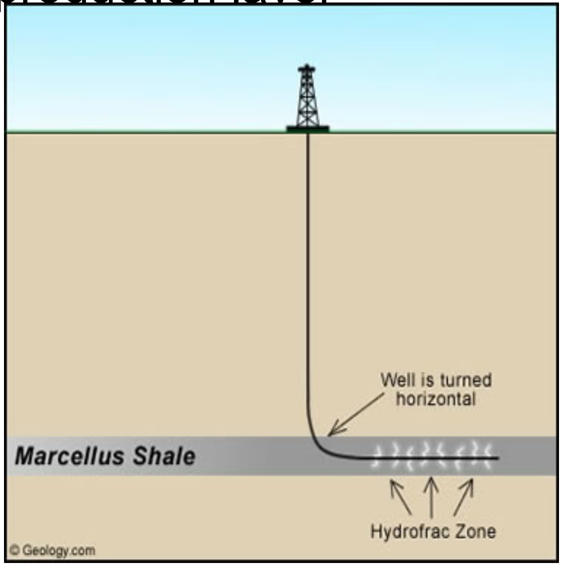
Powering mini implants ◀

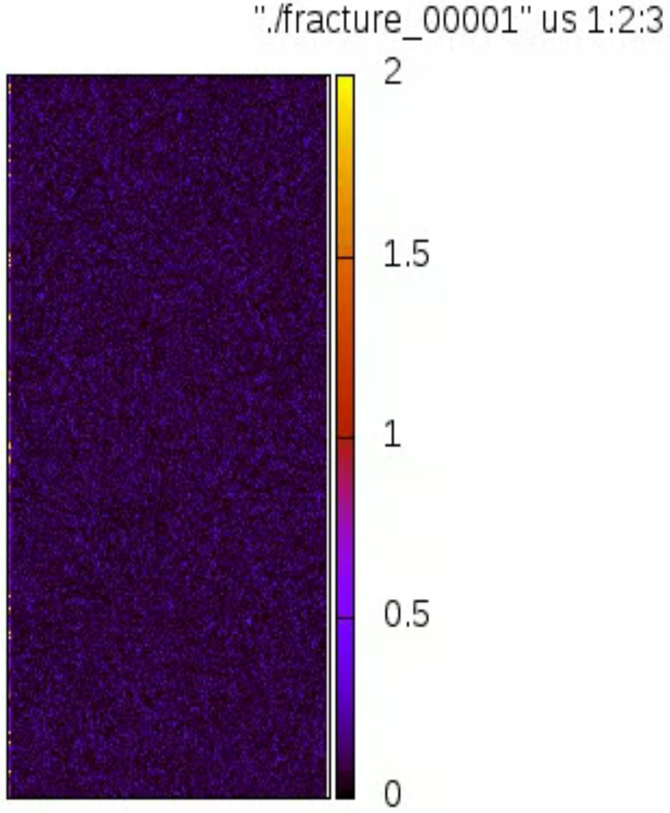
Mercury's magnetism ◀

Modeling the Fracking Process

Line Source Model

Model of a fracture driven by a line pressure source as would be the case in a horizontal well in a thick production layer





Statistical Analysis: An Example

Correlation Function

Growth of frack away from pressure source for a line source model: Correlation analysis

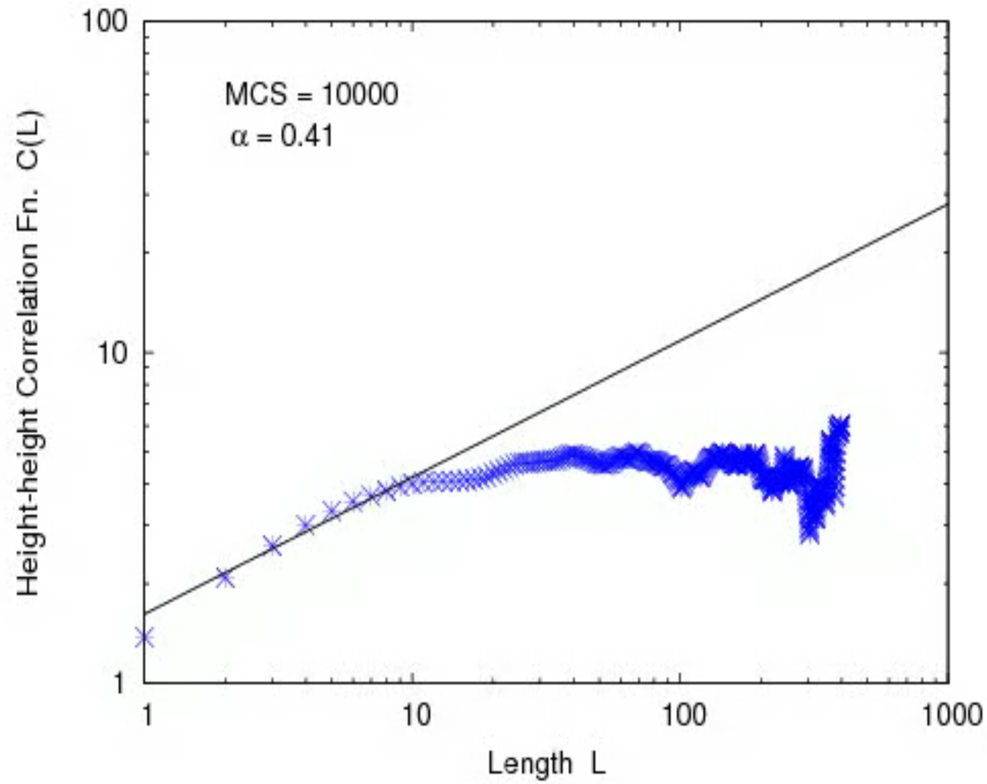
(see, e.g., Barabasi and Stanley, 1995)

KPZ Equation:

$$\frac{\partial h(\boldsymbol{x},t)}{\partial t} = \nu \nabla^2 h + \frac{\lambda}{2} (\nabla h)^2 + \eta(\boldsymbol{x},t)$$

Interface width:

$$w^2(L,t) \equiv \left\langle \left[h(\boldsymbol{x},t) - \langle h(\boldsymbol{x},t) \rangle_L \right]^2 \right\rangle$$

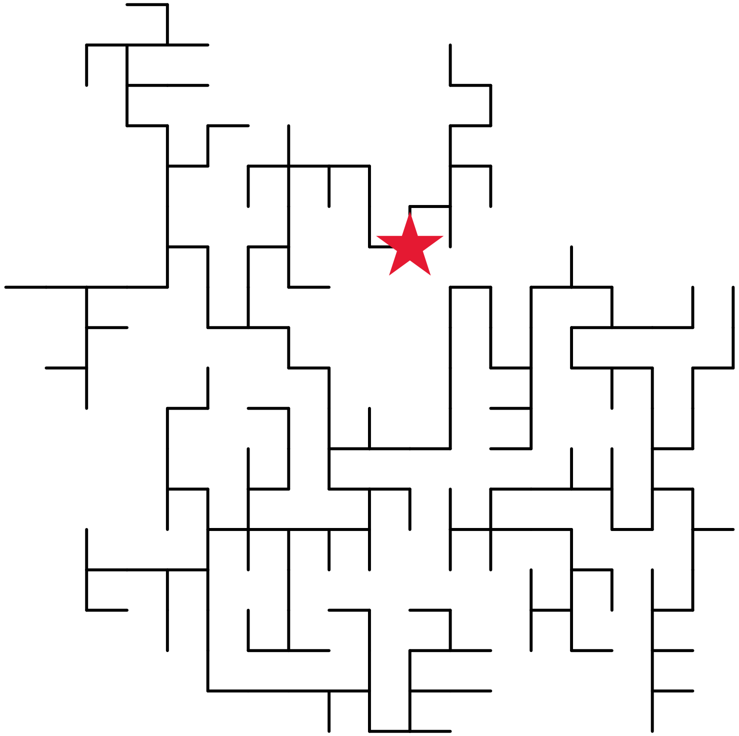


Scaling relation: $w(L,t) \sim L^{\alpha}$

We expect: $\alpha \sim 0.5 \quad (KPZ)$

Invasion Percolation in d=2

Produces a fractal fracture network.



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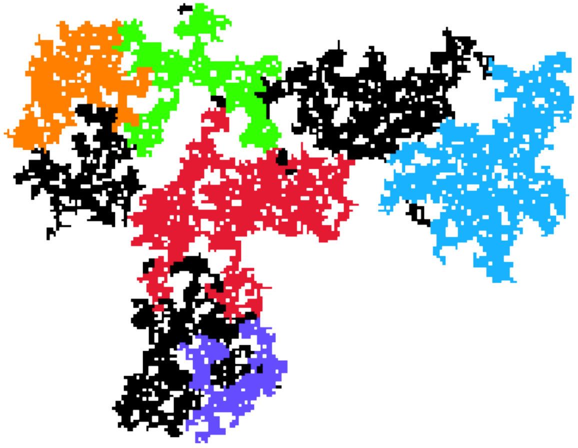
“Bursts”

Bursts are regions connected by relatively weak bonds.



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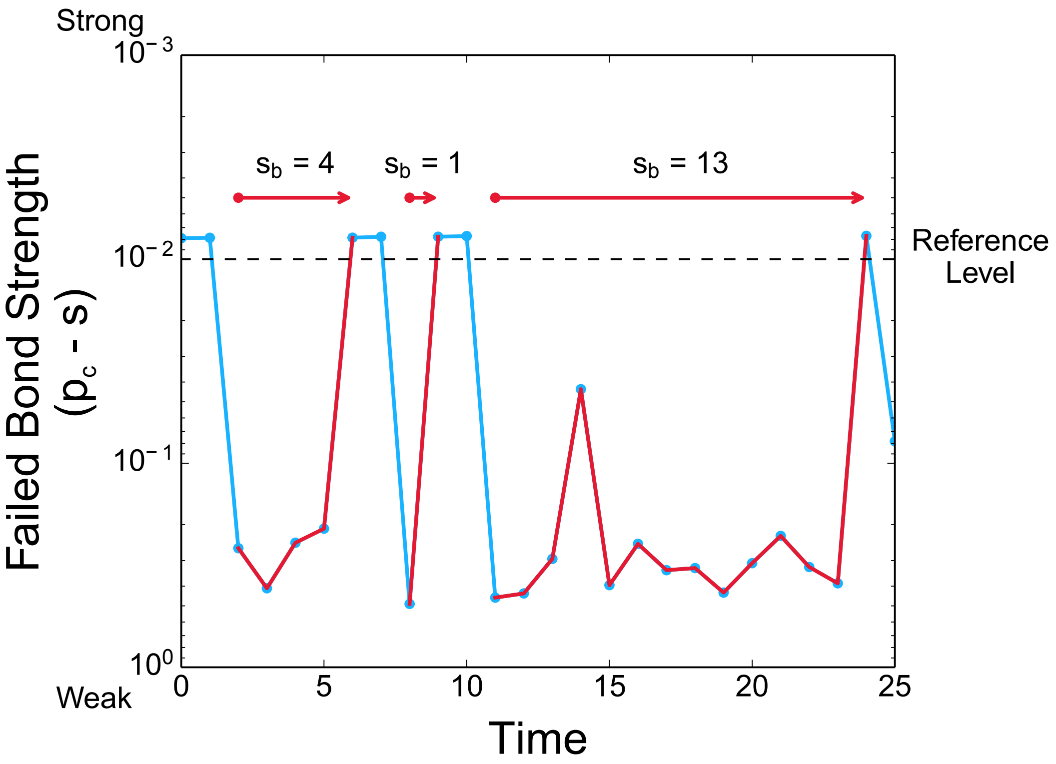
Time Dependence

Growth occurs in bursts.



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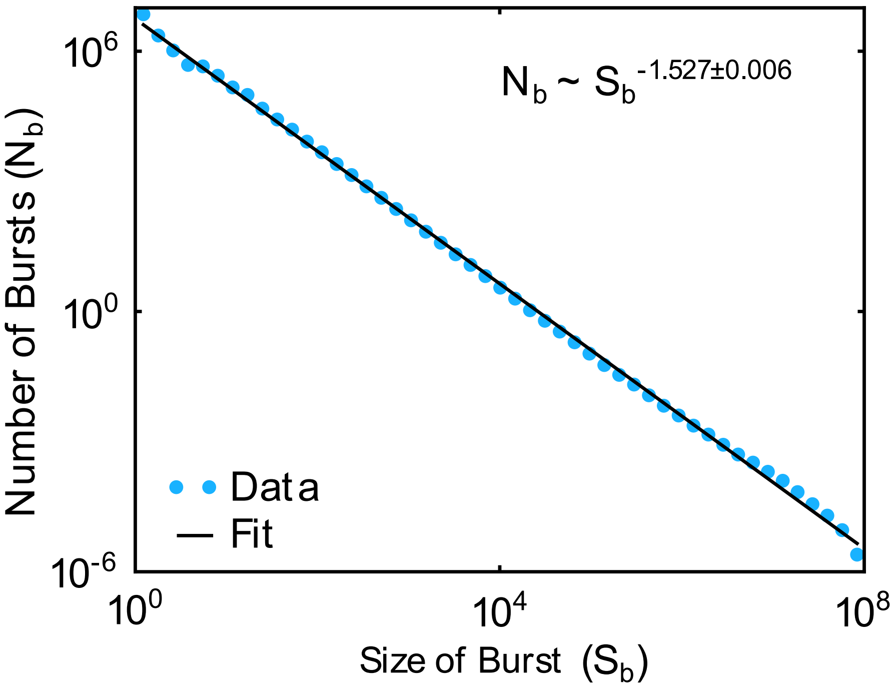
Scaling

Bursts follow a power-law size distribution.



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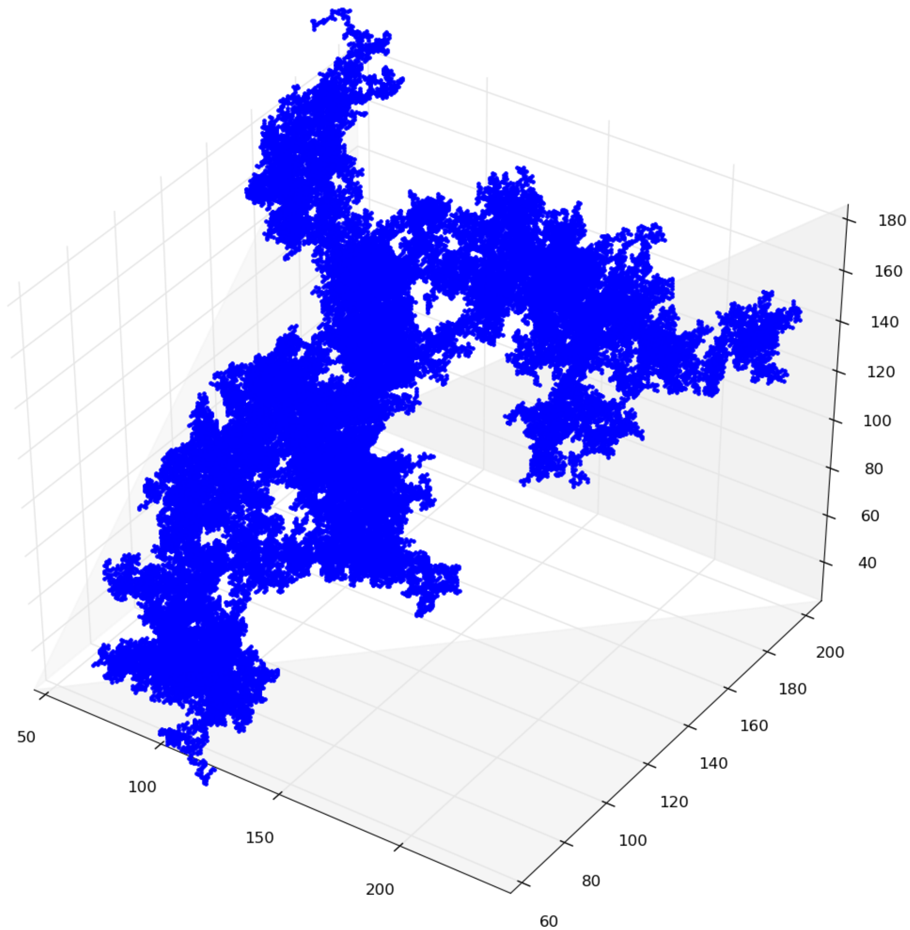
Invasion Percolation Cluster in d=3



Web-Based e-Science for the Physics of Disasters

Online Tools for Global Disaster Risk Management, Research, Communication, Cooperation, and Response

Credit: NHK

John B Rundle

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NatCatSERVICE

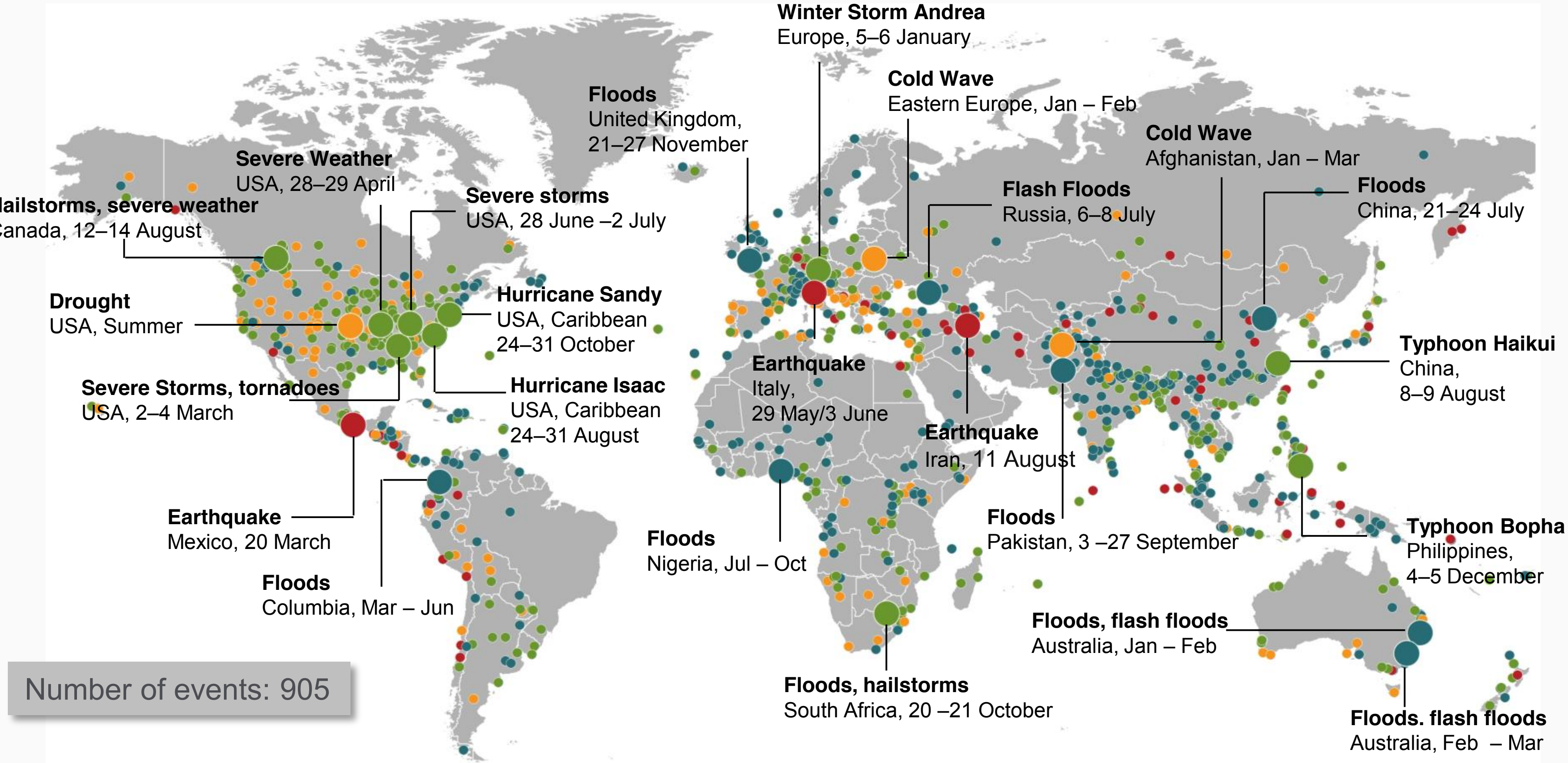
Natural Catastrophes 2012

World map

Impacts

Loss Trends (Munich Re, 2012)

Munich RE



○ **Natural catastrophes**	● **Geophysical events** (earthquake, tsunami, volcanic activity)	● **Hydrological events** (flood, mass movement)
◯ **Selection of significant Natural catastrophes**	● **Meteorological events** (storm)	● **Climatological events** (extreme temperature, drought, wildfire)

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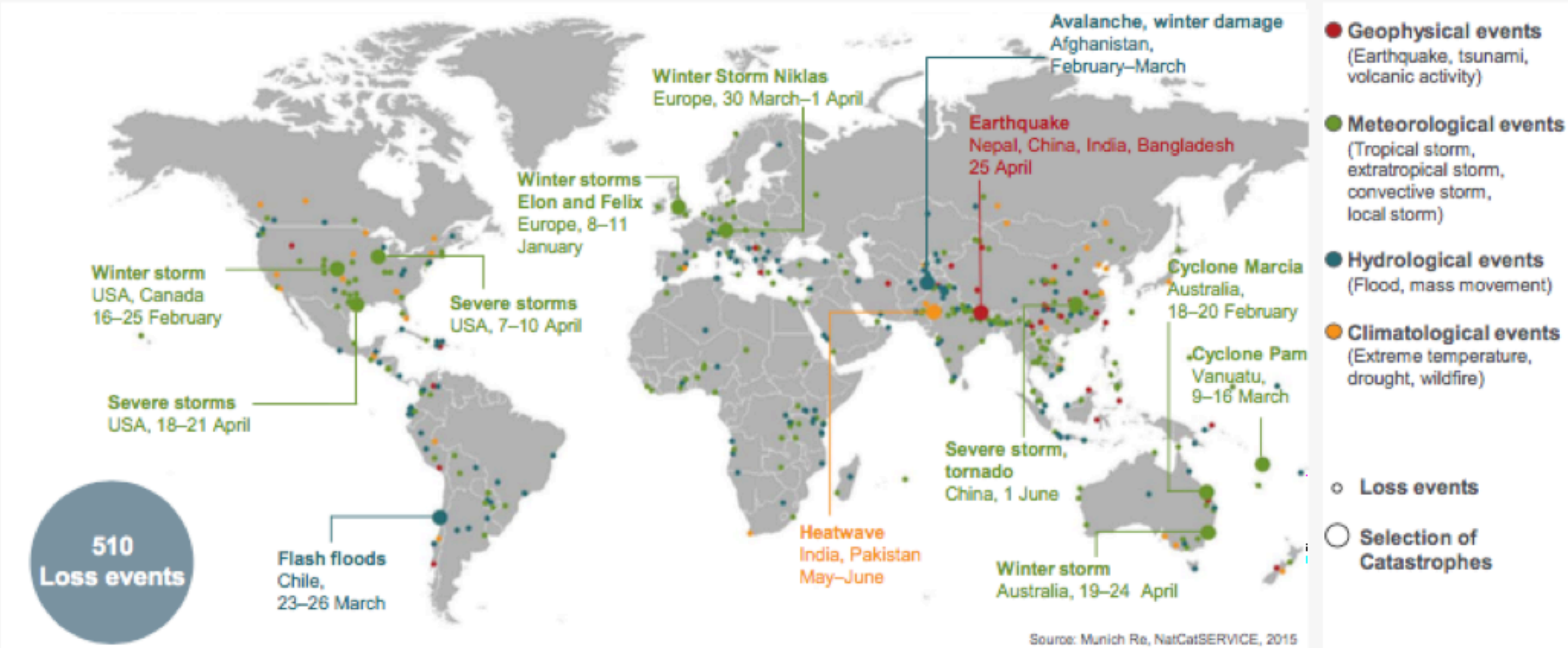
Global Natural Catastrophe Update

Loss events worldwide Jan – June 2015

Geographical overview

Munich RE



Source: Geo Risks Research, NatCatSERVICE – As at July 2015

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Costliest natural catastrophes since 1980
Ranked by insured losses

Munich RE

Year	Event	Region	Insured loss US$m (in original values)
2005	Hurricane Katrina	USA	60,500
2011	EQ, tsunami	Japan	40,000
2012	Hurricane Sandy	USA, Caribbean	29,500
2008	Hurricane Ike	USA, Caribbean	18,500
1992	Hurricane Andrew	USA	17,000
2011	EQ Christchurch	New Zealand	16,500
2011	Floods	Thailand	16,000
1994	EQ Northridge	USA	15,300
2005	Hurricane Wilma	USA, Caribbean	12,500
2012	Drought	USA	12,000

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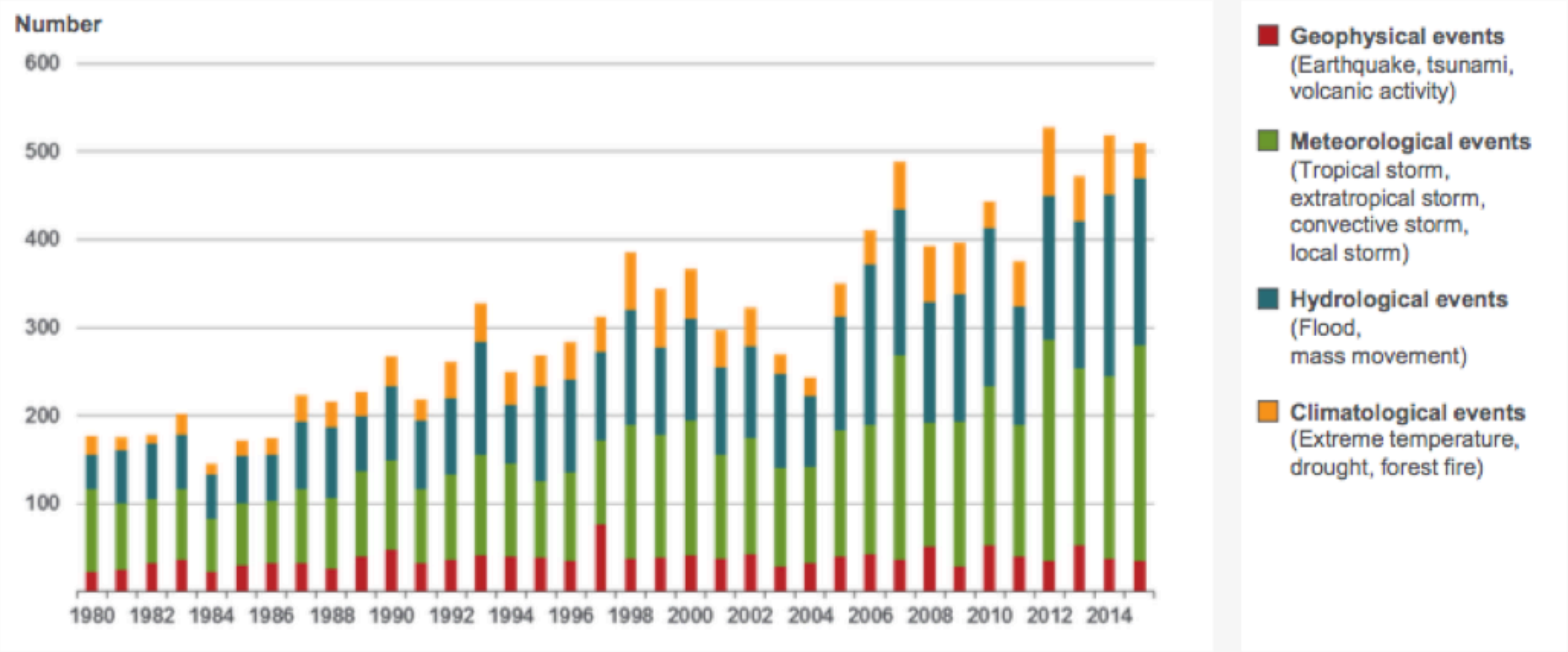
Global Natural Catastrophe Update

Loss events worldwide 1980 – 2015

Number of events (January – June only)

Munich RE



Source: Munich Re, NatCatSERVICE – As at July 2015

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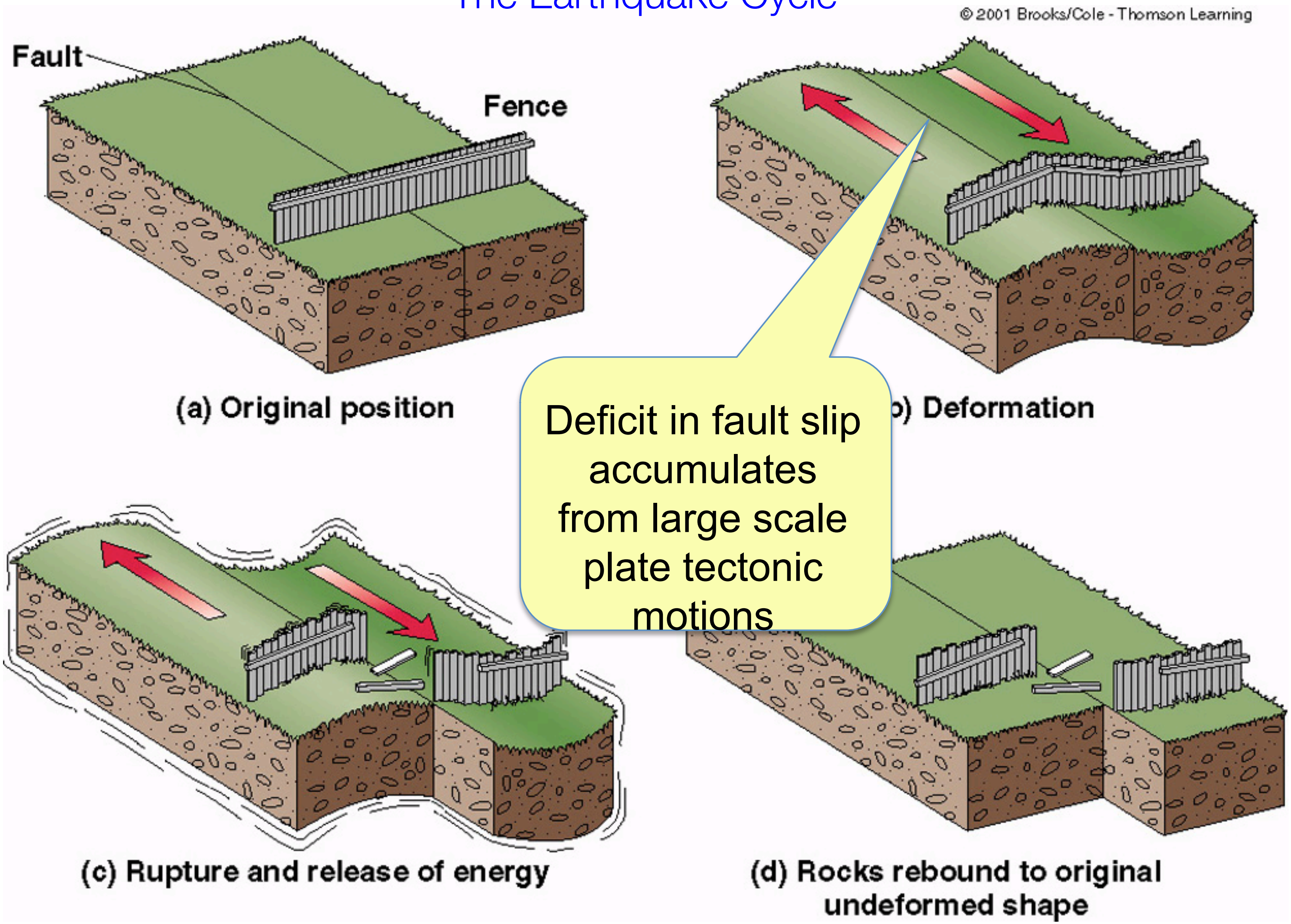
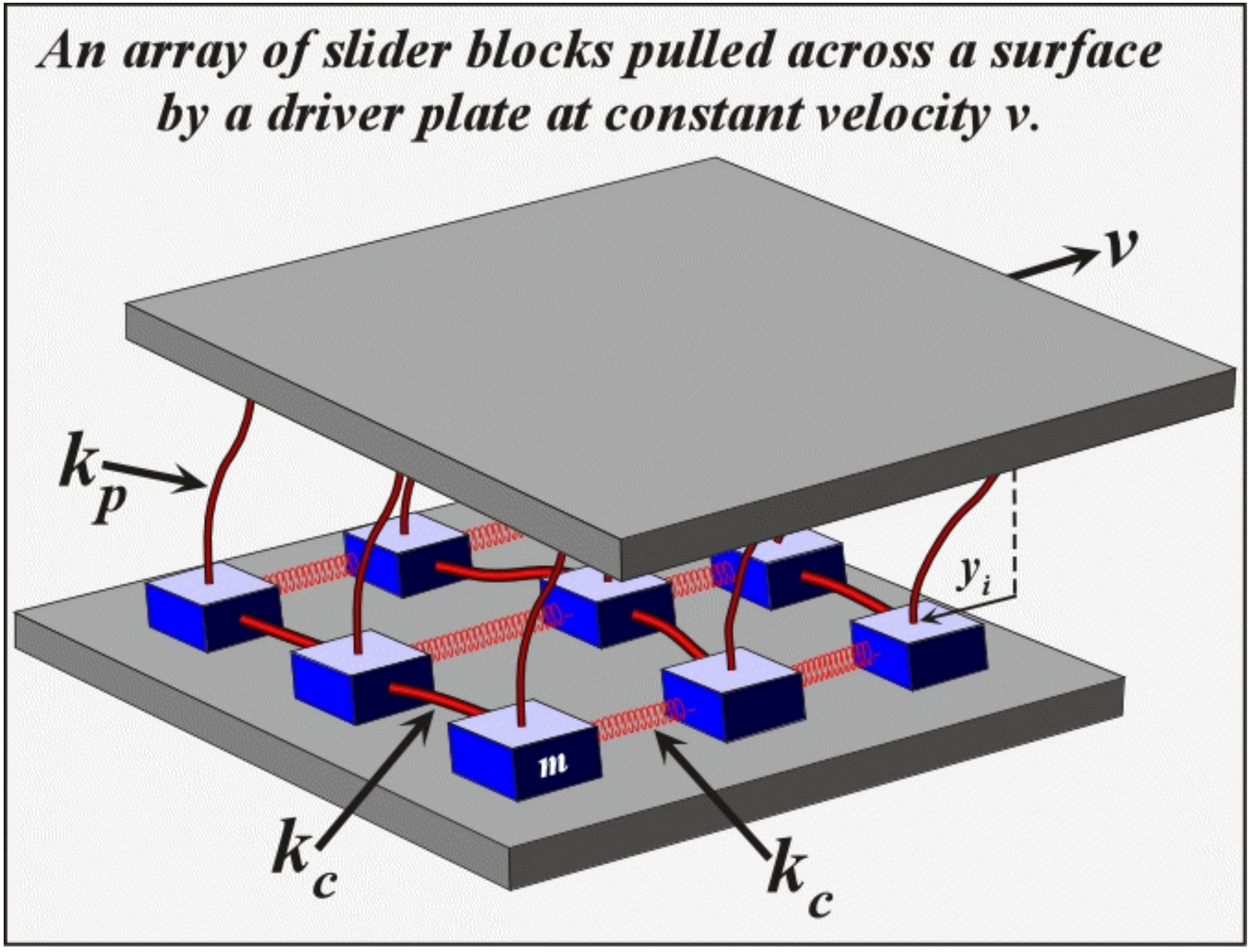
Earthquakes:
The Earthquake Cycle



Earthquake Models

A simple model of an earthquake fault - CA Model

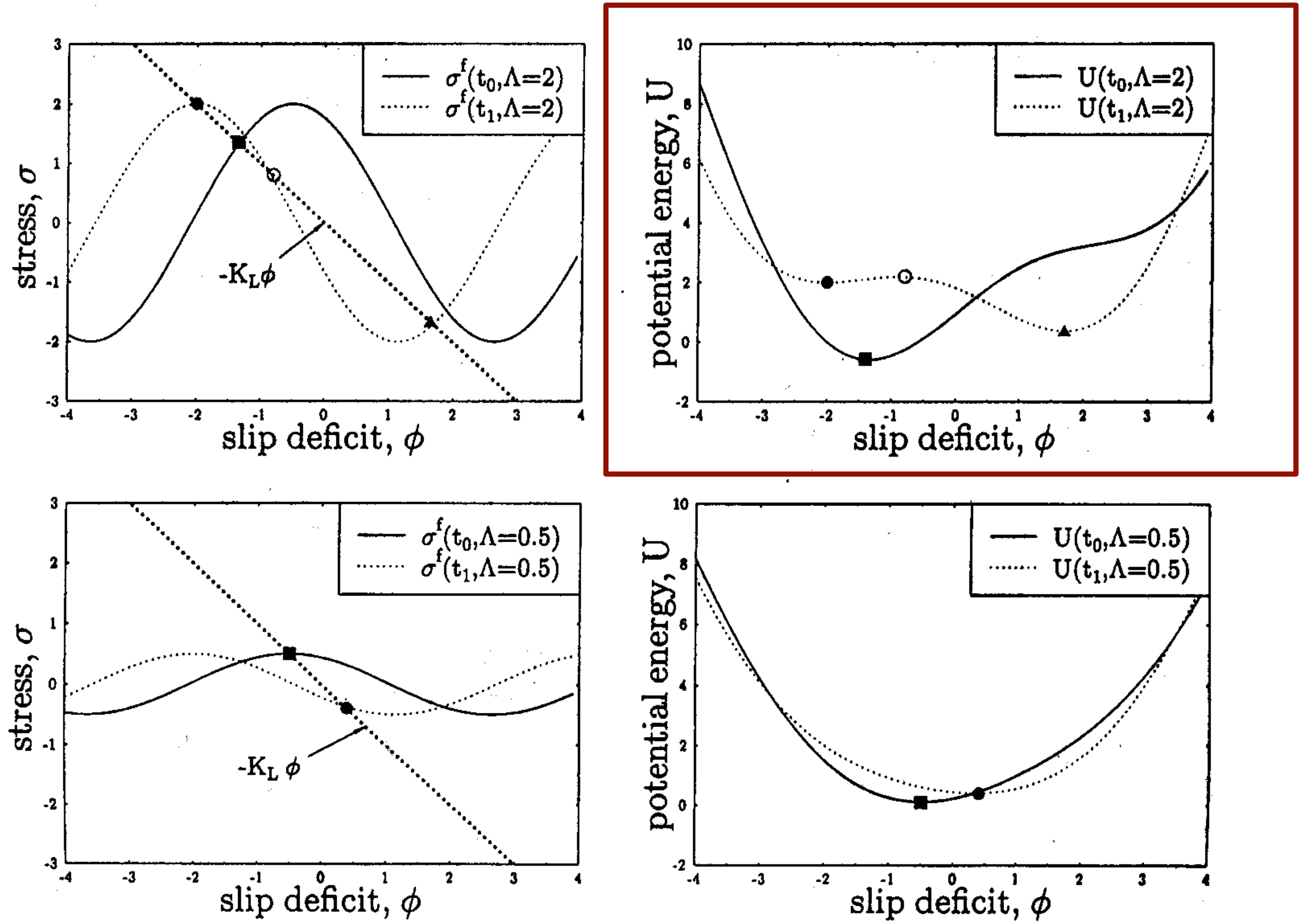
(R Burridge and L Knopoff, BSSA, 1967; JBR & DD Jackson, BSSA, 1977)



De-Pinning Transition Model for Earthquakes

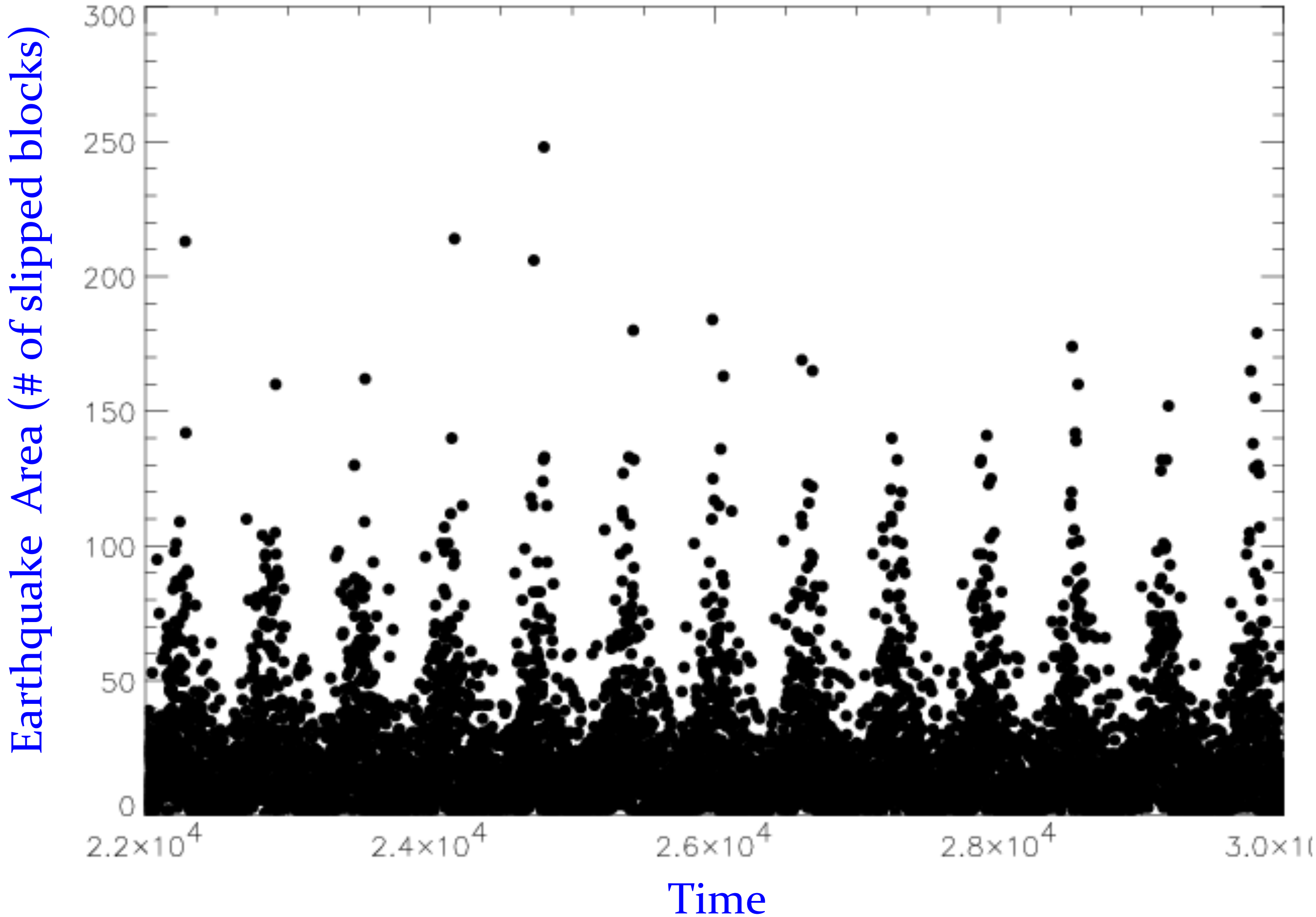
Model has the physics of a first order phase transition (metastability).

JBR et al., Phys. Rev. Lett., 76, 4285, 1996.



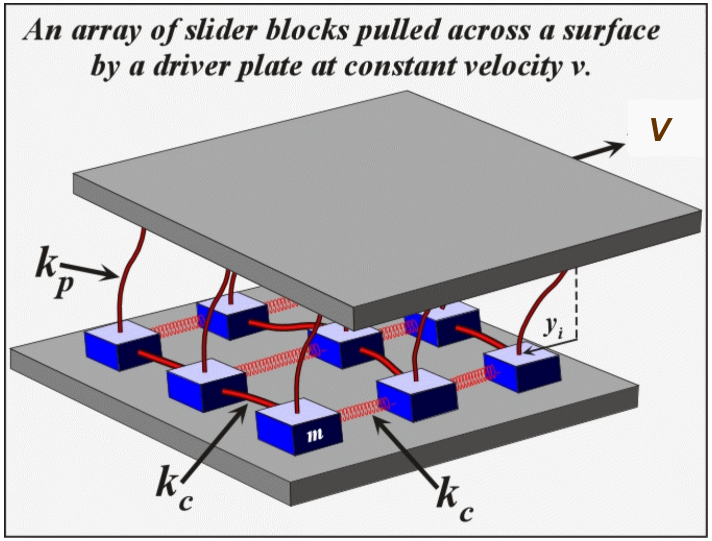
De-Pinning Transition Model for Earthquakes

Numerical Simulations of Earthquake Occurrence



Slider Block Model with Incomplete Healing:

A Model for Friction

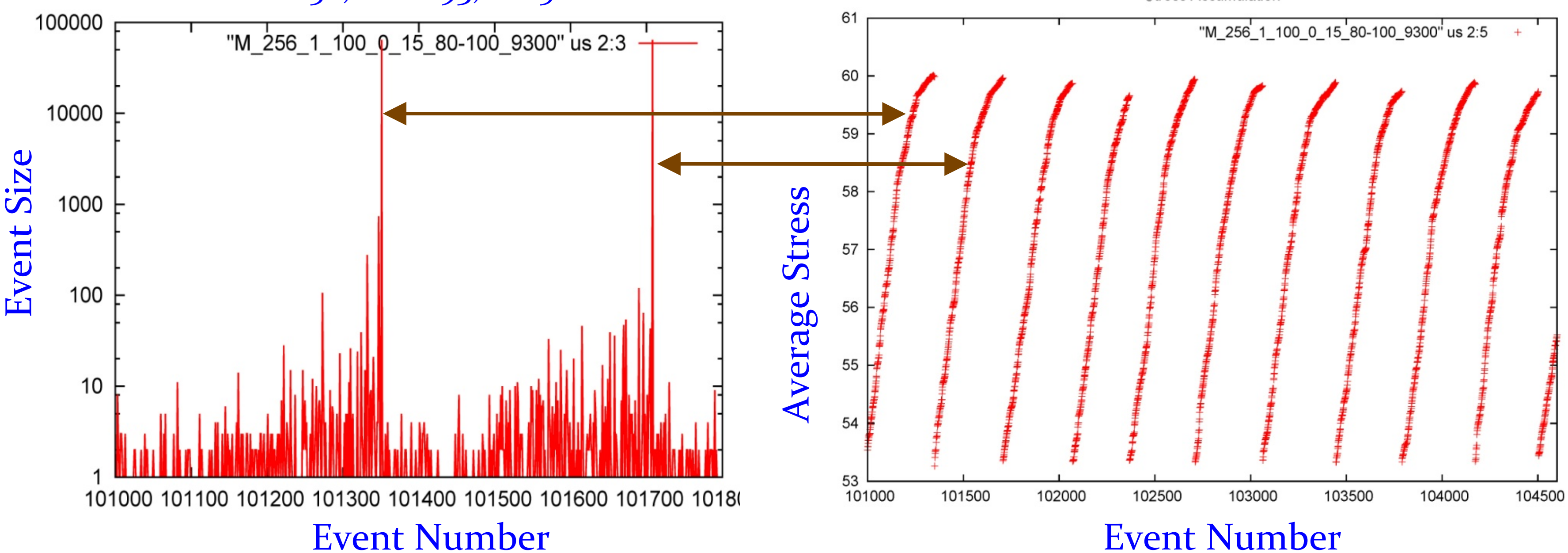


We consider a slider block model with:

- ❖ Incomplete healing during rupture
- ❖ Complete healing following rupture
- ❖ Healing during rupture is characterized by a fractional parameter $h < 1$
- ❖ Range of interaction R
- ❖ Lattice size L

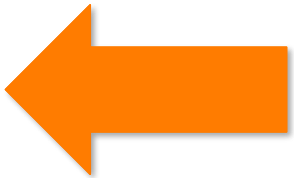
We find close similarities to random site percolation (Leath algorithm)

L=256, h = 0.93, R=15



The Four Phases of a Disaster

- Anticipation
- Mitigation
- Response
- Recovery



The World Wide Web:
Information Delivery via Two Web Sites

- Tools and Data for the Public

  www.openhazards.com

- Research Web Site with OpenHazards forecasts, earthquake fault system simulations & InSAR data:

  www.quakesim.c

Forecasts

*Co-Winner of the
2012 NASA Software of the Year Award
As Announced Today (2012/09/21)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NASA Home > News & Features > News Topics > Looking at Earth > Features
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QuakeSim and NASA Mobile App Win NASA Software Award 09.20.12

PASADENA, Calif. - NASA software that models the behavior of earthquake faults to improve earthquake forecasting and our understanding of earthquake processes, and NASA's first mobile application are co-winners of NASA's 2012 Software of the Year Award. The award recognizes innovative software technologies that significantly improve the agency's exploration of space and maximize scientific discovery on Earth.

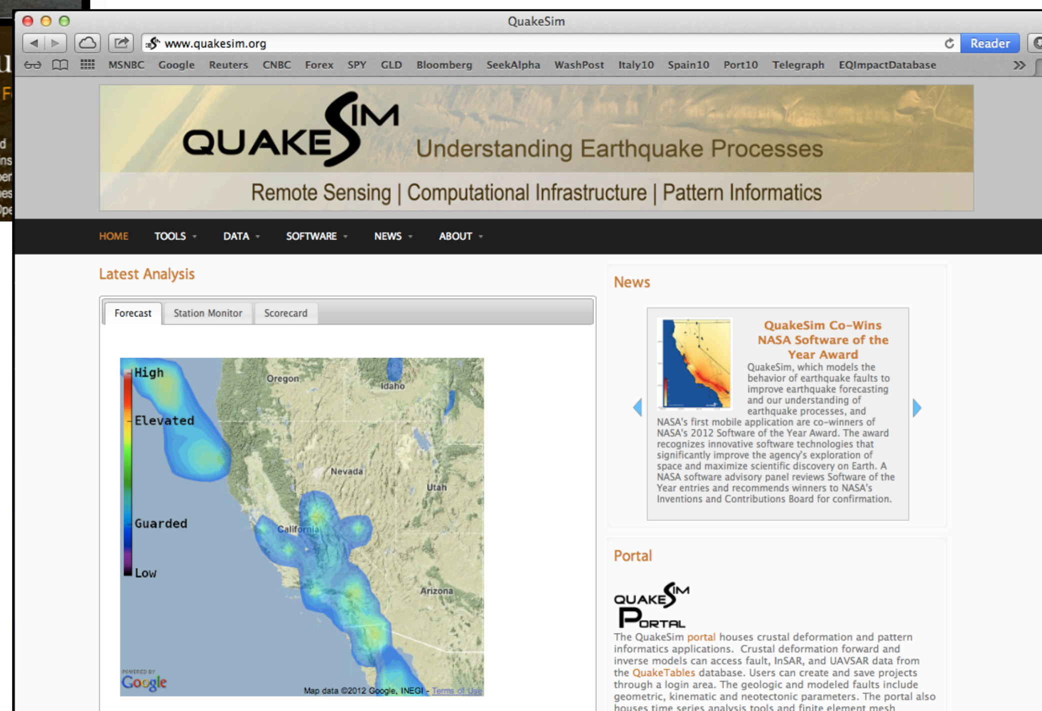
QuakeSim, developed at NASA's Jet Propulsion Laboratory in Pasadena, Calif., is a comprehensive, state-of-the-art software tool for simulating and understanding earthquake fault processes and improving earthquake forecasting. Initiated in 2002, QuakeSim uses NASA remote sensing and other earthquake-related data to simulate and model the behavior of faults in 3-D both individually and as part of complex, interacting systems. This provides long-term histories of fault behavior that can be used for statistical evaluation. QuakeSim also is used to identify regions of increased earthquake probabilities called hotspots.

Studies have shown QuakeSim to be the most accurate tool of its kind for intermediate earthquake forecasting and detecting the subtle, transient deformation in Earth's crust that precedes and follows earthquakes. Its varied applications include scientific studies, developing earthquake hazard maps that can be used for targeted retrofitting of earthquake-vulnerable structures, providing input for damage and loss estimates after earthquakes, guiding disaster response efforts, and studying fluid changes in reservoirs, among

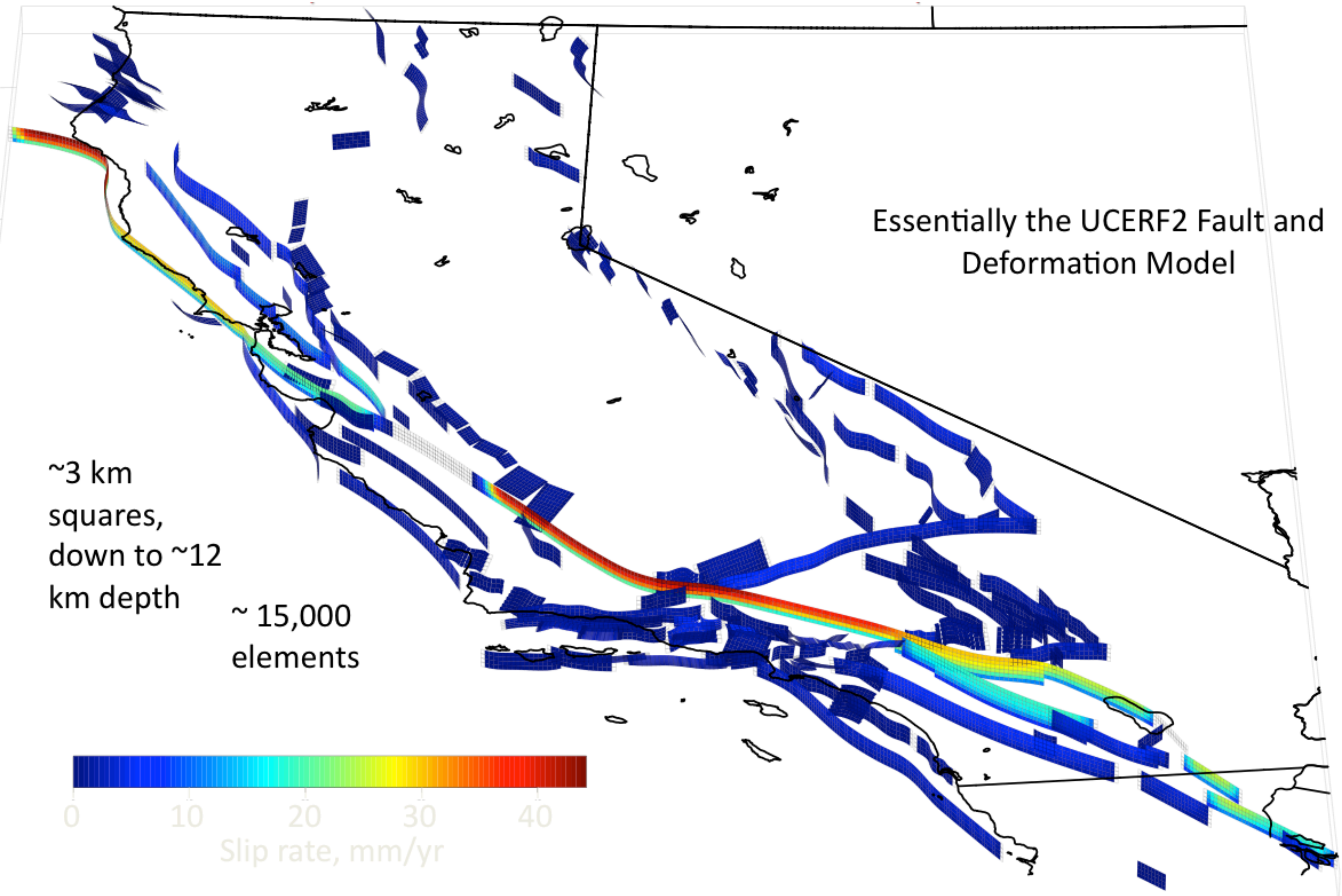
The total ground deformation caused by a simulated magnitude 8.0 earthquake on the San Andreas fault. Image credit:

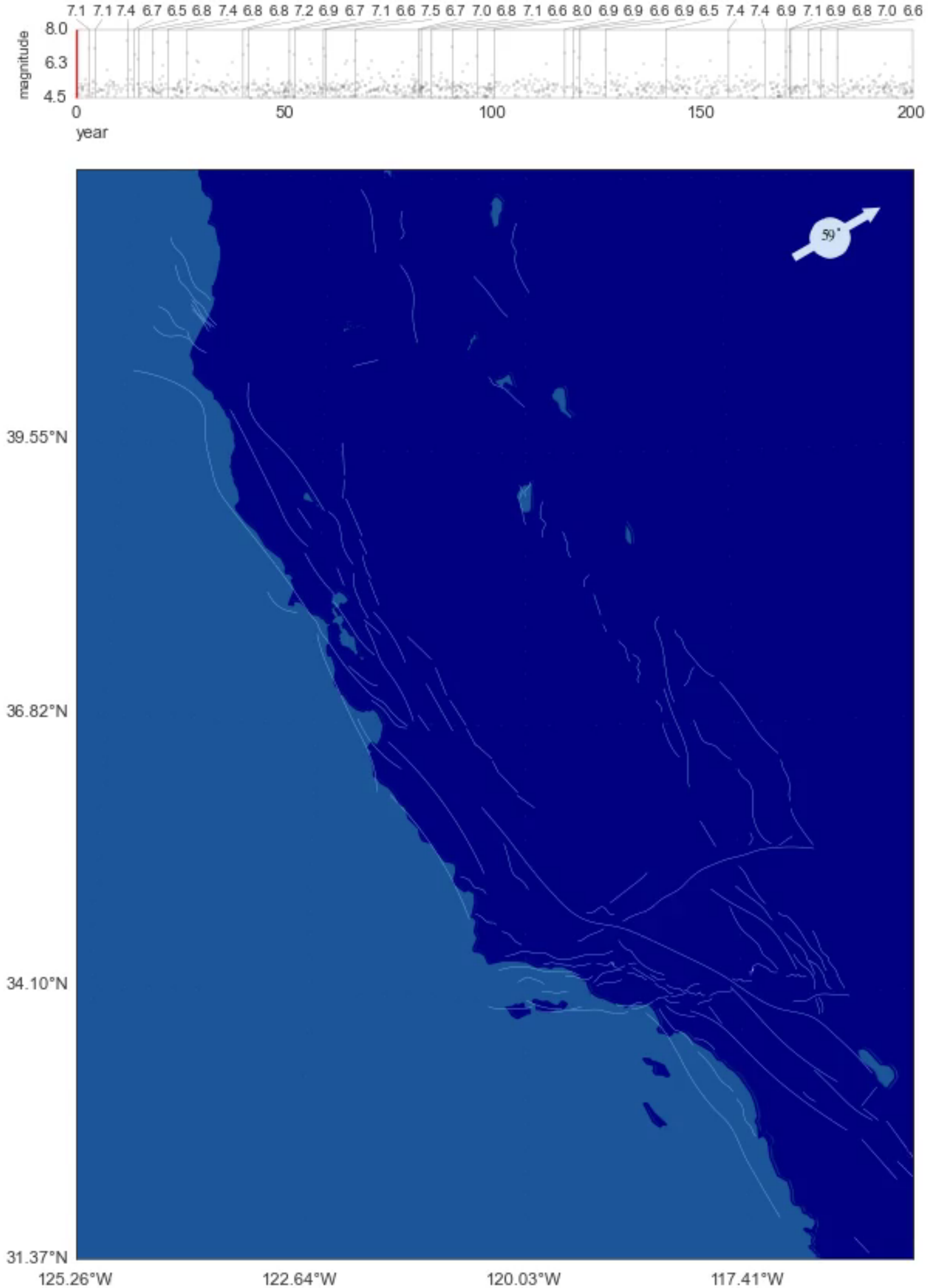
OpenHazards:
A Resource for the Public

QuakeSim:
A Resource for Researchers



Simulating the Dynamics of a Complex Earthquake Fault System

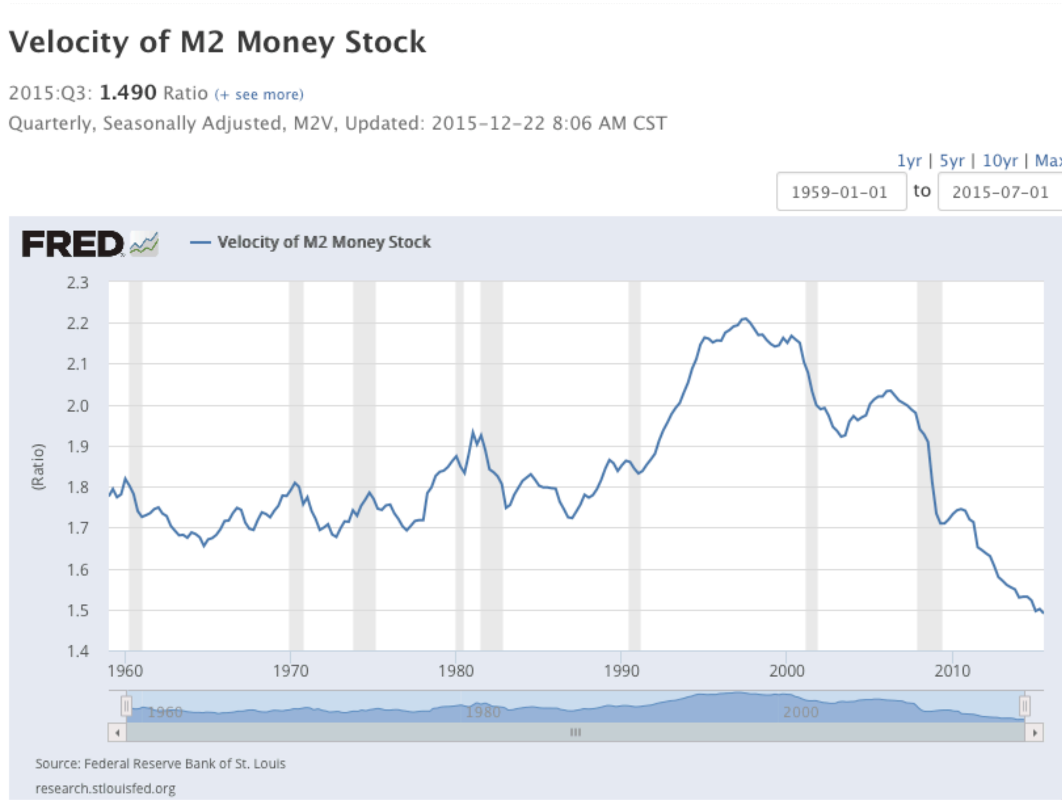



7.1 7.1 7.4 6.7 6.5 6.8 7.4 6.8 6.8 7.2 6.9 6.7 7.1 6.6 7.5 6.7 7.0 6.8 7.1 6.6 8.0 6.9 6.9 6.6 6.9 6.5 7.4 7.4 6.9 7.1 6.9 6.8 7.0 6.6
magnitude
8.0
6.3
4.5
0
50
100
150
200
year
59°
39.55°N
36.82°N
34.10°N
31.37°N
125.26°W
122.64°W
120.03°W
117.41°W

Computational Finance

Example of Data Science

- The velocity of money is the frequency at which one unit of currency is used to purchase domestically- produced goods and services within a given time period
- The broad M2 component includes M1 (currency in circulation) in addition to saving deposits, certificates of deposit (less than $100,000), and money market deposits for individuals.



Calculated as the ratio of quarterly nominal GDP (http://research.stlouisfed.org/fred2/series/GDP) to the quarterly average of M2 money stock (http://research.stlouisfed.org/fred2/series/M2SL).

S&P 500 Index of US Stocks

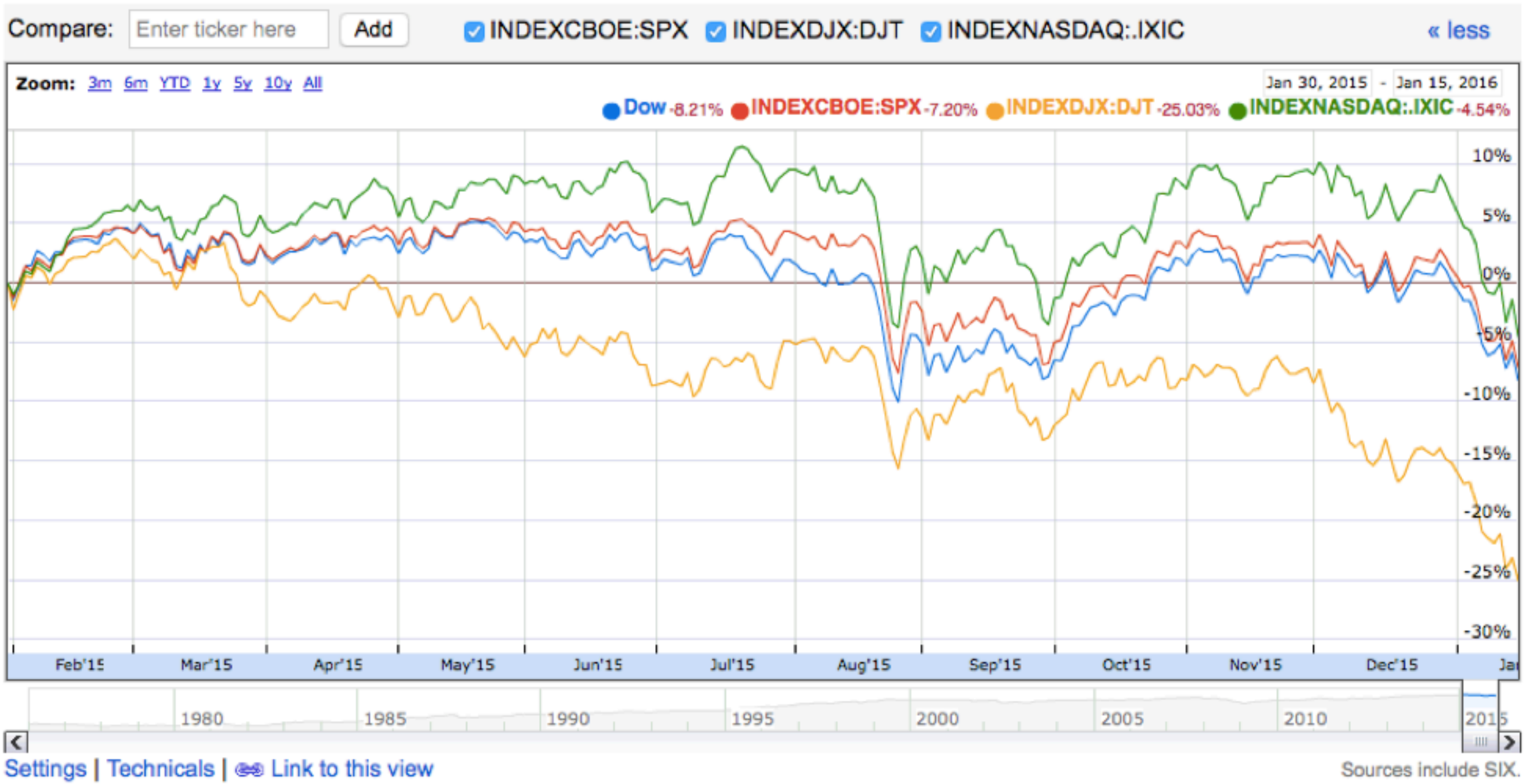
"Order Parameter"

Implied Volatility of S&P 500

“Temperature”

Simple Classical Model: “Dow Theory”

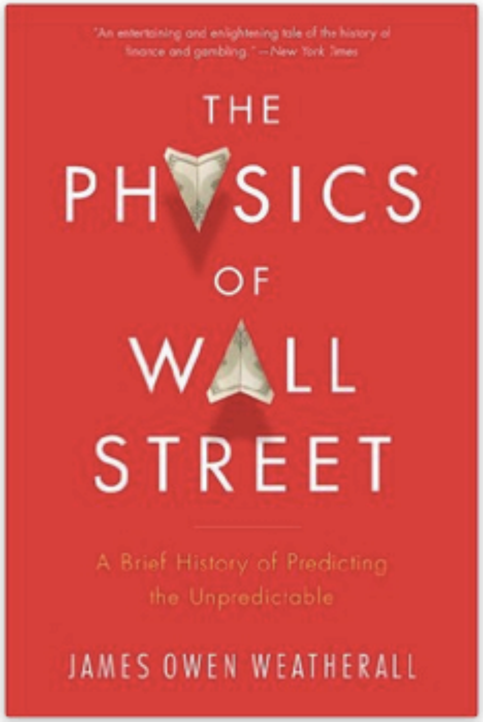
Downturn in Dow Transports (DJT) precedes downturn in Dow Industrials (DJI)



SPX, Dow, Dow Transports and Nasdaq

Close

Look inside



Audible Narration

The Physics of Wall Street: A Brief History of Predicting the Unpredictable Kindle Edition

by James Owen Weatherall (Author)

104 customer reviews

See all 7 formats and editions

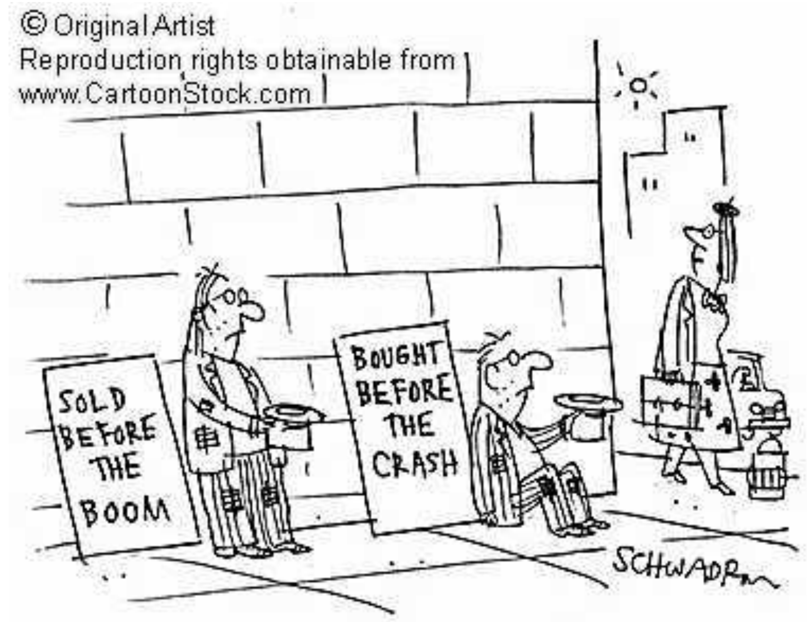
Kindle	Hardcover	Paperback
$10.99	$21.72 Prime	$13.82 Prime
Read with Our **Free App**	51 Used from $0.01 42 New from $1.96 1 Collectible from $10.50	47 Used from $1.86 49 New from $1.99 1 Collectible from $12.99

After the economic meltdown of 2008, Warren Buffett famously warned, "beware of geeks bearing formulas." But as James Weatherall demonstrates, not all geeks are created equal. While many of the mathematicians and software engineers on Wall Street failed when their abstractions turned ugly in practice, a special breed of physicists has a much deeper history of revolutionizing finance. Taking us from fin-de-siècle Paris to Rat Pack-era Las Vegas, from

Read more

Models:

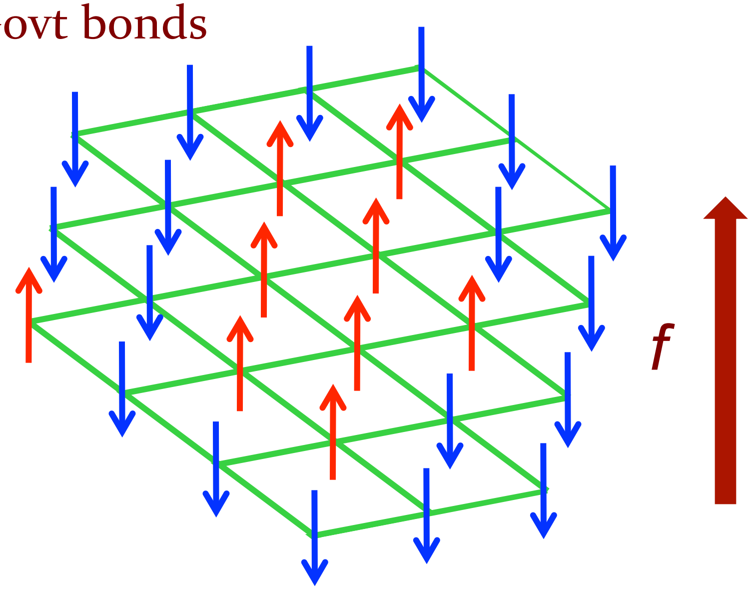
Dynamics of Financial Markets



Investors are arrows :

↑ Owns only Govt. bonds ↓ Owns only stocks

[illegible] is the fraction of total money deployed in Govt bonds



f is the real Fed funds rate

Volatility V plays the role of "temperature"

For example, we might have V [illegible] (VIX)

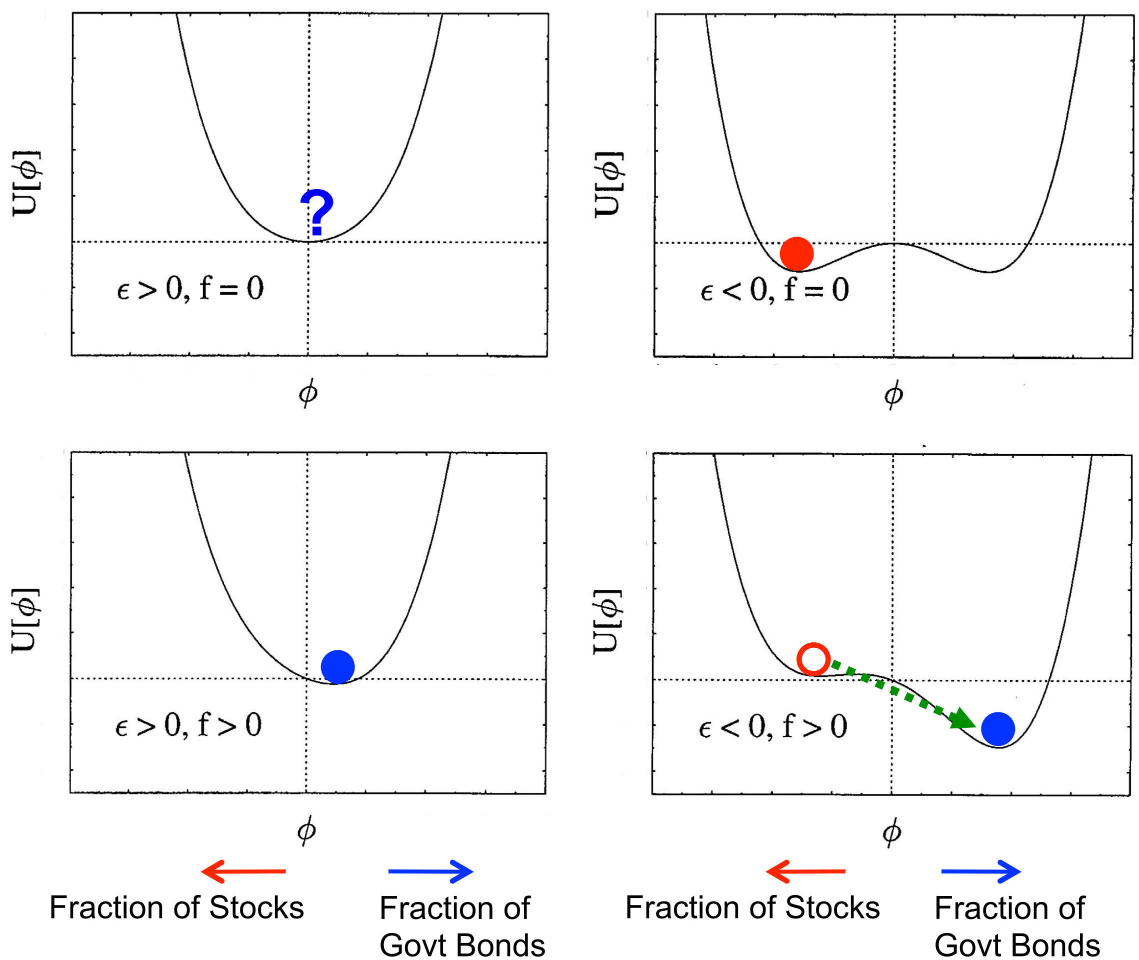
Investors "interact" with neighbors, strength J

Market Potential

U[[illegible]]

Phase Transitions in Financial Markets

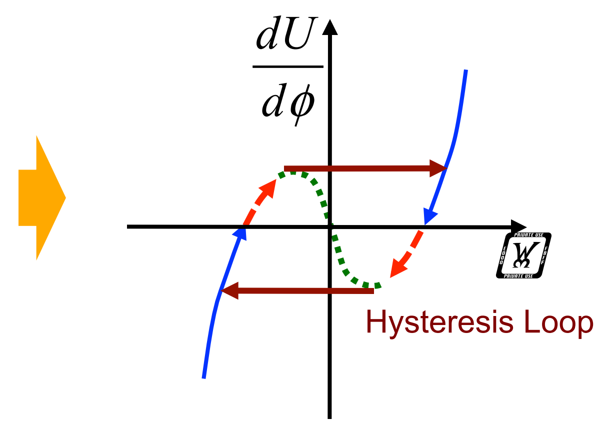
First order phase transitions – metastability, nucleation, hysteresis



f: Real Fed funds rate

V: Volatility (VIX)

$(V - V_C)$



● Bonds ● ○ Stocks

Market Potential $U[\phi] = \varepsilon\, \phi^2 + \alpha\, \phi^4 - f\, \phi$

Markets and Phase Transitions

Before a 1st Order Phase Transition

Transition occurs via nucleation and growth of bubbles

Classical: Correlation lengths and times are small
Nonclassical: Correlation lengths and times

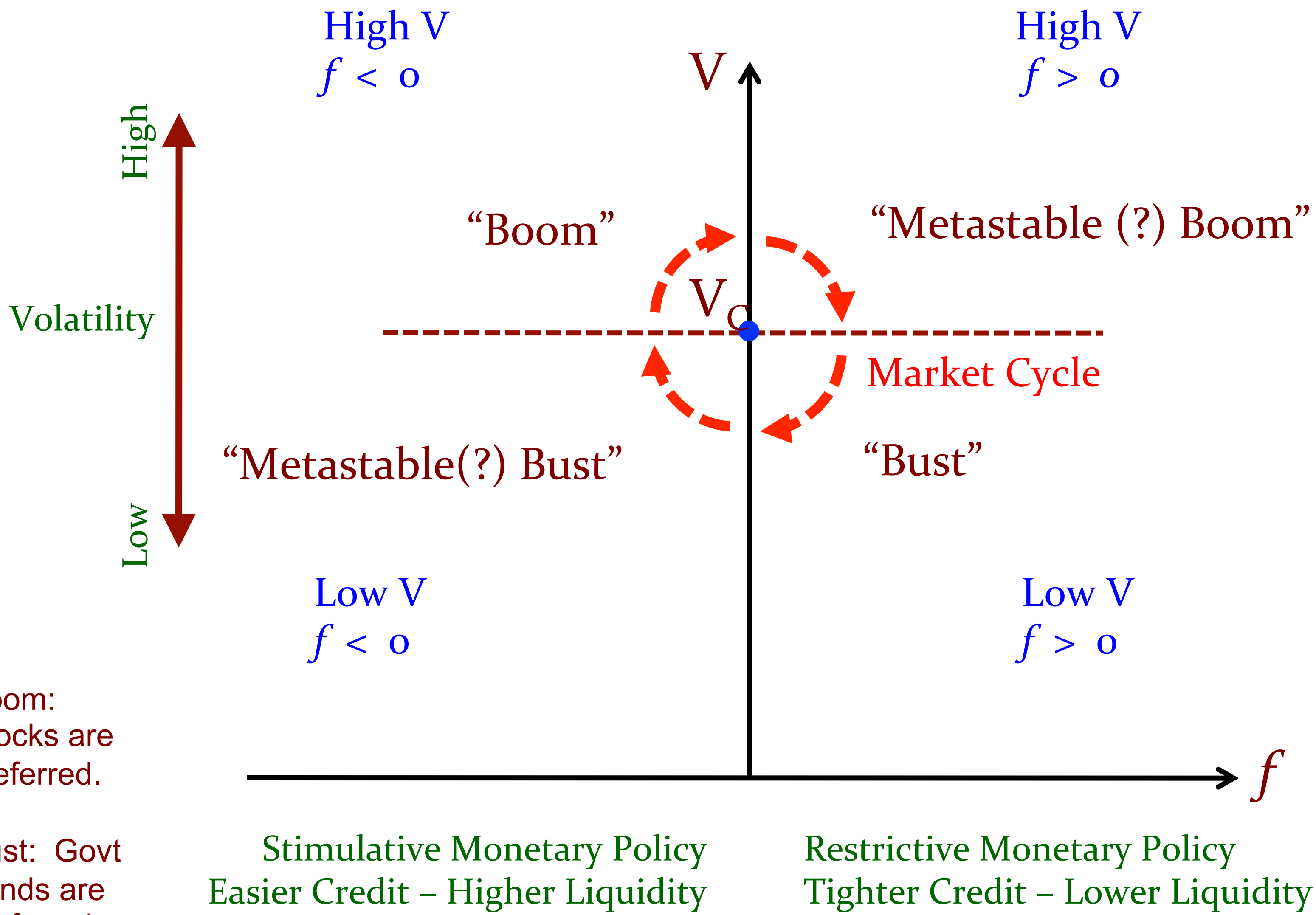
Large fluctuations (volatility is high) – Ginzburg Criterion

Risk function (of bubble formation):

Related to nucleation rate of bubbles,
Lifetime in the metastable state is inverse of nucleation rate

Scaling (fat tail) exponents can be calculated

Simple Phase Diagram for the Markets

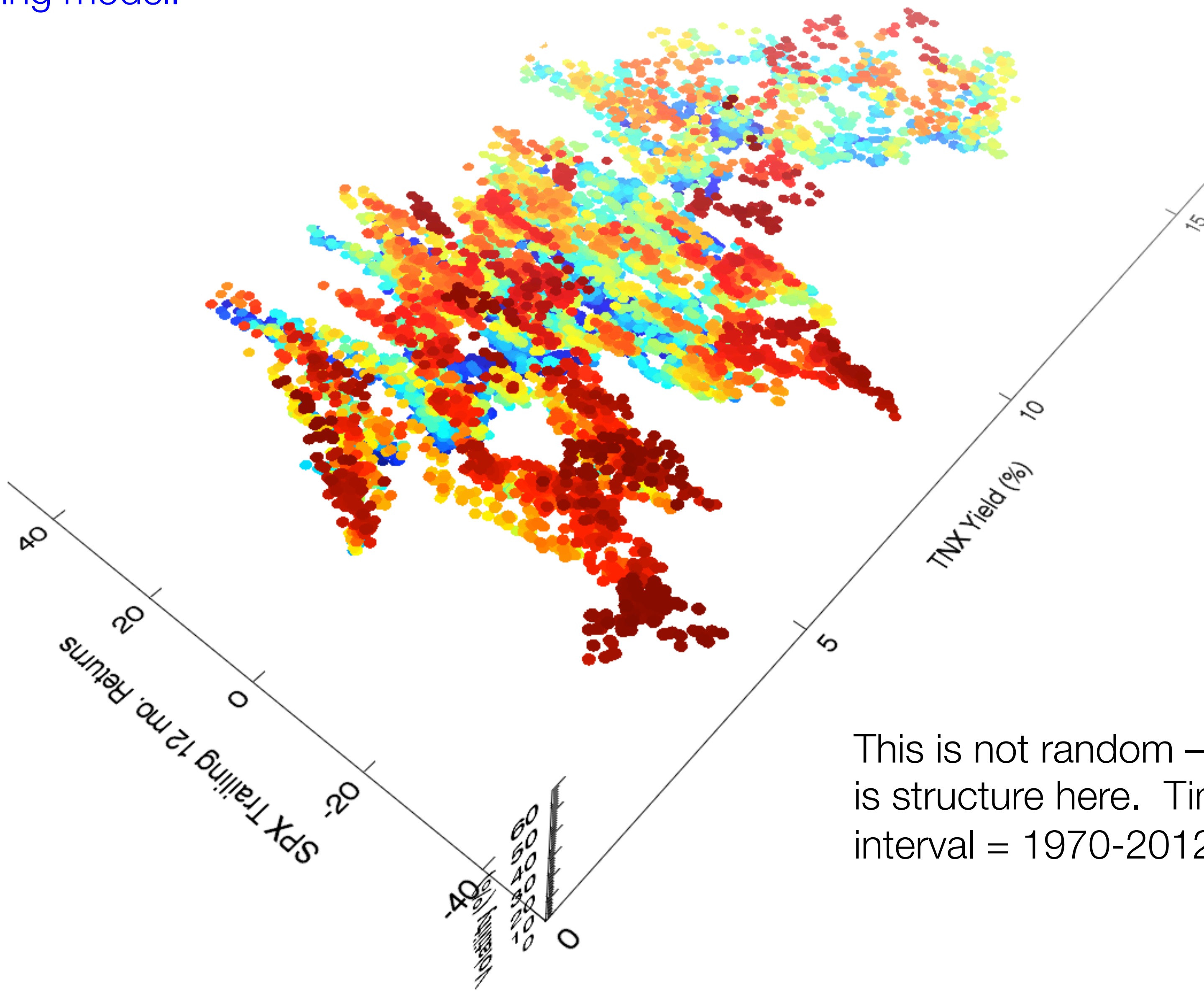


Boom: Stocks are preferred.

Bust: Govt bonds are preferred

Attractor for the S&P 500

The dynamics are a bit more complex than a simple Ising model!



This is not random – there is structure here. Time interval = 1970-2012