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Predictive Understanding of Extreme Events in Nature and Society
Part 2. Yet untapped possibilities:
"the paradox of want amidst plenty"

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Predictive Understanding of Extreme Events in Nature and Society. *Part 2. Yet untapped* possibilities: "the paradox of want amidst plenty".

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Prediction based on the premonitory patterns has been explored for the following extreme events

Published results

Earthquakes
Volcanic Eruptions
Geo-engineering
Recessions (onset and end)
Unemployment surge
Homicide surges
Electoral change of governing party

Work in progress

Magnetosphere storms
Armed conflicts
Carbon Isotopes
Environmental crises
Business and management
Mineral deposits
Price of oil and gas
...

"Learning by doing": Ample tutorial materials and software are accumulated in ICTP

Although prediction of extreme event is necessary for the very survival of our civilization, only a small part of available and relevant data, models, theories, and practical experience is used in the quest for prediction. That is a "paradox of want amidst plenty" (contemporaries' view of the Great Depression).

Prediction considered is based on premonitory patterns – the system's behaviour patterns that emerge more frequently as an extreme event draws near. Premonitory patterns signal that the system is destabilizing so that probability of an extreme event is increasing.

J. Stock "/Prediction of recessions/ requires fitting non-linear, high-dimensional models to a handful of observations generated by a possibly non-stationary economic environment… The evidence presented here suggests that these simple binary transformations of economic indicators have significant predictive content for recession. It is striking that these models in which the information in the data is reduced to binary indicators has predictive contents comparable to or, in many cases, better than that of more conventional models."

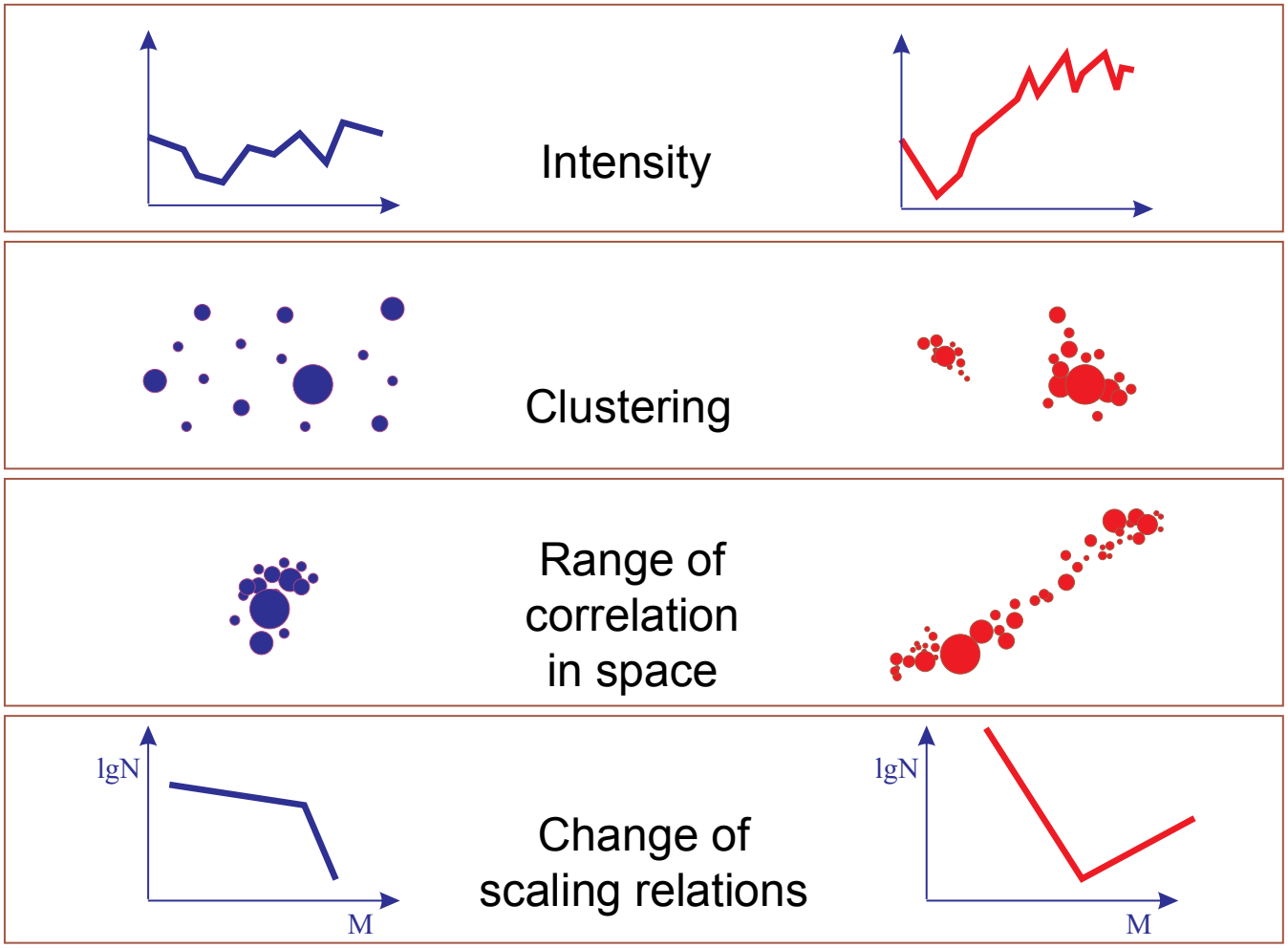
Premonitory patterns and extreme event are the manifestations of the same underlying process: the development of the system in multiple time, space and energy scales. Accordingly – most if not all observable fields are potentially useful for prediction. Paradox: most of them remain untapped (Jeffreys' maxim)

Four paradigms of prediction research

Detection of premonitory patterns is facilitated by their common features that had been established by numerical modelling, theory and data analysis. **The same paradox**.

Four paradigms (cont.)

I. Major kinds of premonitory patterns



Non-precursory state

Precursory state

Four paradigms (cont.)

II. LONG-RANGE CORRELATIONS

Generation of an extreme event is *not confined to its future location*.

For example, preparation of an earthquake with magnitude M and linear source dimension L(M) involves area of diameter up to 10L **(Keilis-Borok and Malinovskaya, 1964; Richter, 1964; Kossobokov et al.,1990; Romanovicz, 1993; Bowman, 1998)**

Preparation of strongest earthquakes extends to global and even astronomical scales **(Press, Briggs, 1975)**

This is inevitable due to premonitory perturbations of large-scale processes:
-- Chandler wobble, Earth rotation, drift of magnetic field **(Press, Briggs)**
-- Plate movements **(Press, Allen)**
-- Ductile lower crust **(Aki)**
-- Mantle flows **(Schubert, Turcotte, Ismail-Zadeh, Soloviev)**

Four paradigms (cont.)

III. SIMILARITY

Premonitory patterns are similar (identical after normalization) in extremely diverse conditions and in a broad range of scales.

Example: In multiple fracturing such a similarity is observed for:

Breakdown of laboratory samples ⇒
⇒ Rockbursts in mines ⇒
⇒ Earthquakes with magnitude from 4.5 to 8+ worldwide ⇒
⇒ Possibly, starquakes, magnitude about 20

Energy range - from few erg to 10^{23} erg, and possibly 10^{41} erg

Four paradigms (cont.)

IV. DUAL NATURE OF PRECURSORS

WHERE IS PHYSICS? /L. Kadanoff/

Some precursors are "universal", common for hierarchical complex systems of different origin. They have been found in statistical mechanics models:

-- Direct, inverse, and colliding cascades (Shnirman M., and Blanter E. Hierarchical Models of Seismicity. In V.I.Keilis-Borok and A.A.Soloviev (eds), Nonlinear Dynamics of the Lithosphere and Earthquake Prediction. Springer-Verlag, Berlin-Heidelberg, 2003: 37-69.

Zaliapin,I., et al. http://www.igpp.ucla.edu/prediction/ref/BDE2.pdf

Gablrielov et al. http://www.igpp.ucla.edu/prediction/ref/CC2.pdf)

-- Diffusion with branching (analytical solution) (Gabrielov et al. http://arxiv.org/abs/0708.1542arXiv:0708.1542v1)

-- Cluster Dynamics (Gabrielov, Sinai, et al. 2008. http://wolfweb.unr.edu/homepage/zal/pubs/GKBSZ08.pdf)

Perpetrators or *witnesses:* Our precursors might predict not an extreme event *per se* but destabilization of the system, which makes it *ripe* for an extreme event. Among proverbial witnesses are straws in the wind preceding a hurricane.

More untapped possibilities

Integrating the data on Earth structure into predicting natural disasters.

Nodes

See lectures by A. Soloviev

Strong earthquakes and other geological disasters nucleate in particularly unstable mosaic structures, called nodes, that are formed around fault intersections or junctions. Roughly put, they are formed due to collisions of the corners of the blocks. **(Mackenzie, Gordon, King, Ranzman…)**

Nodes interact through a fault network and control the stability of the lithosphere by the geometric incompatibility between the geometry of a fault network and its kinematics **(Gabrielov, KB, Jackson)**

Strong earthquakes nucleate only in the nodes, moreover, in specific nodes that have been pattern recognized in many regions worldwide.

Nodes are textbook knowledge in structural geology and mineral prospecting but, for some incomprehensible reason, they are usually ignored in seismology with dire consequences.

Nodes, cont.

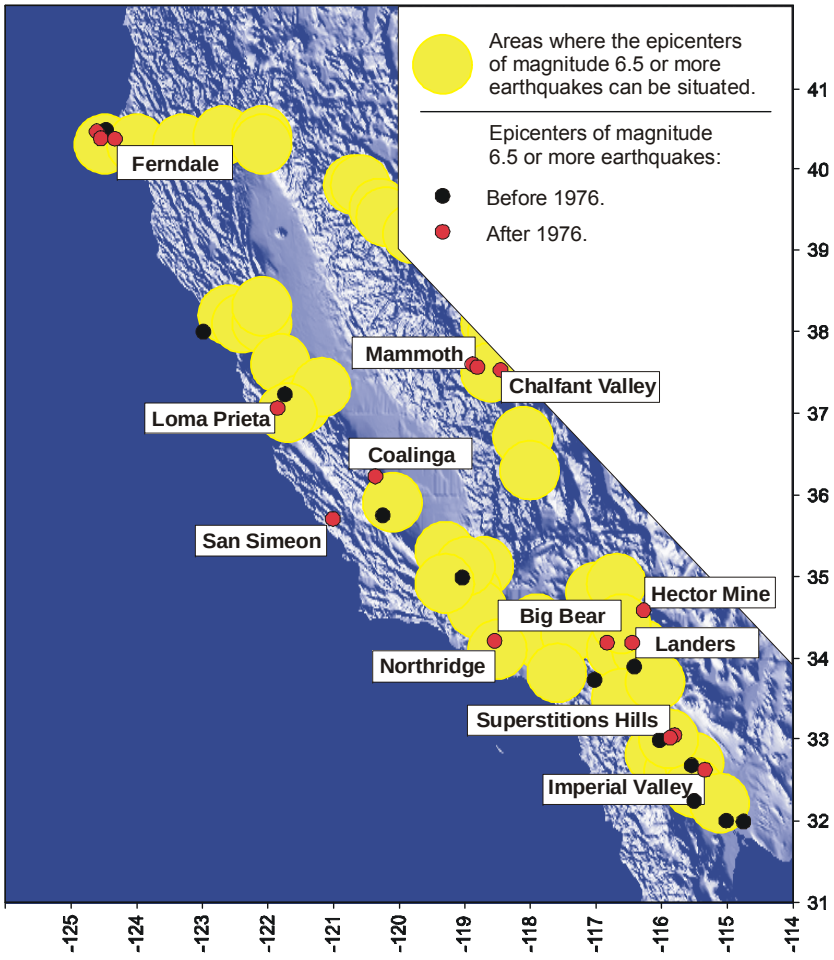
An example: recognition of nodes where earthquakes with M ≥ 6.5 may nucleate in California and adjacent parts of Nevada.

After publication (1976), five such earthquakes, including Northridge and Hector Mine, occurred in predicted areas where they had been previously unknown.

One failure to recognize:
San Simeon earthquake.

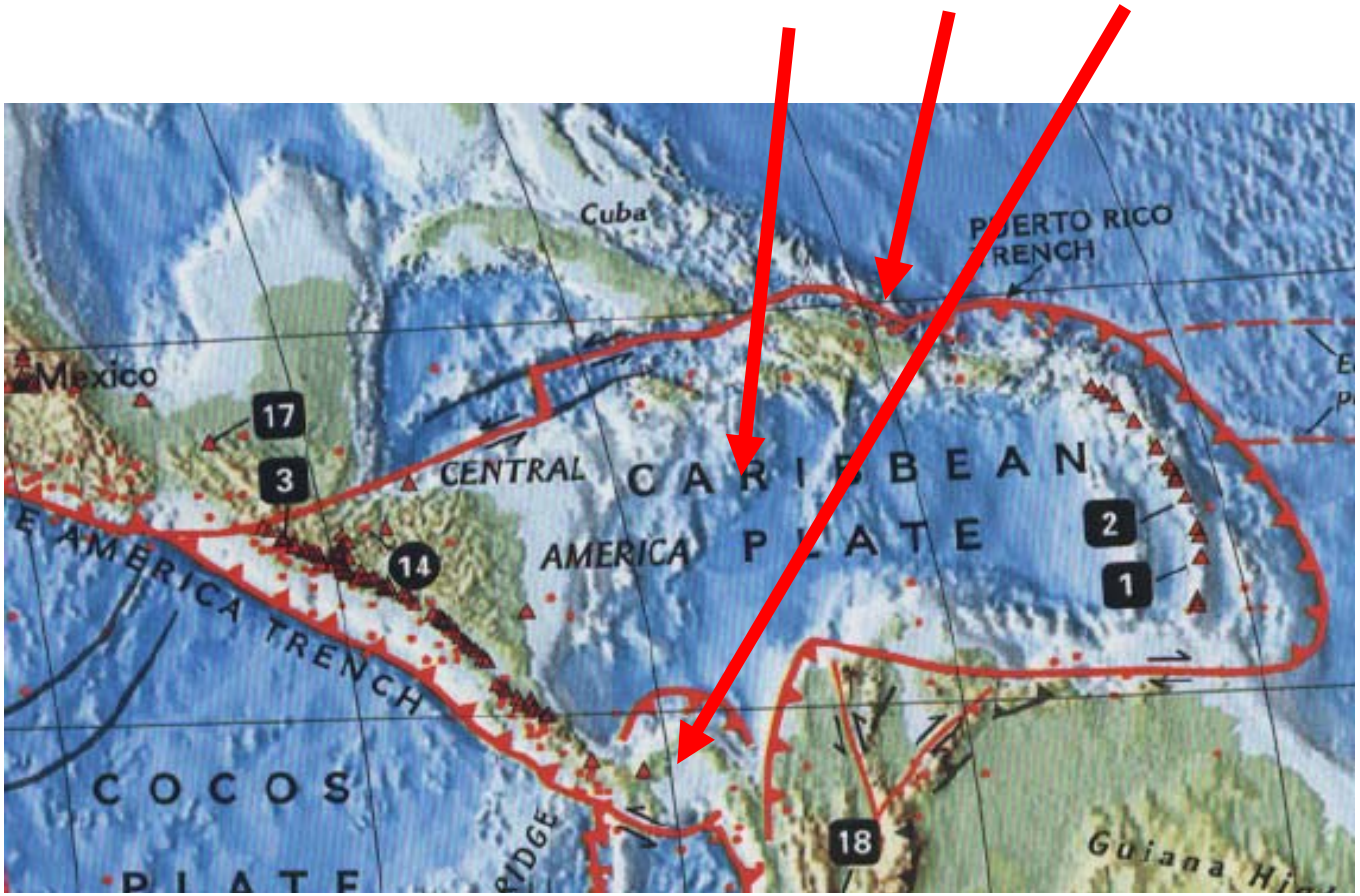
Note: Diablo Canyon NPP, Northridge quake

I. Gelfand, Sh. Guberman, V. Keilis-Borok, L. Knopoff, F. Press, E. Ranzman, I. Rotwain, A. Sadovsky, 1976. Phys. Earth Planet. Inter. 11:227–83



More untapped possibilities for geological disasters prediction

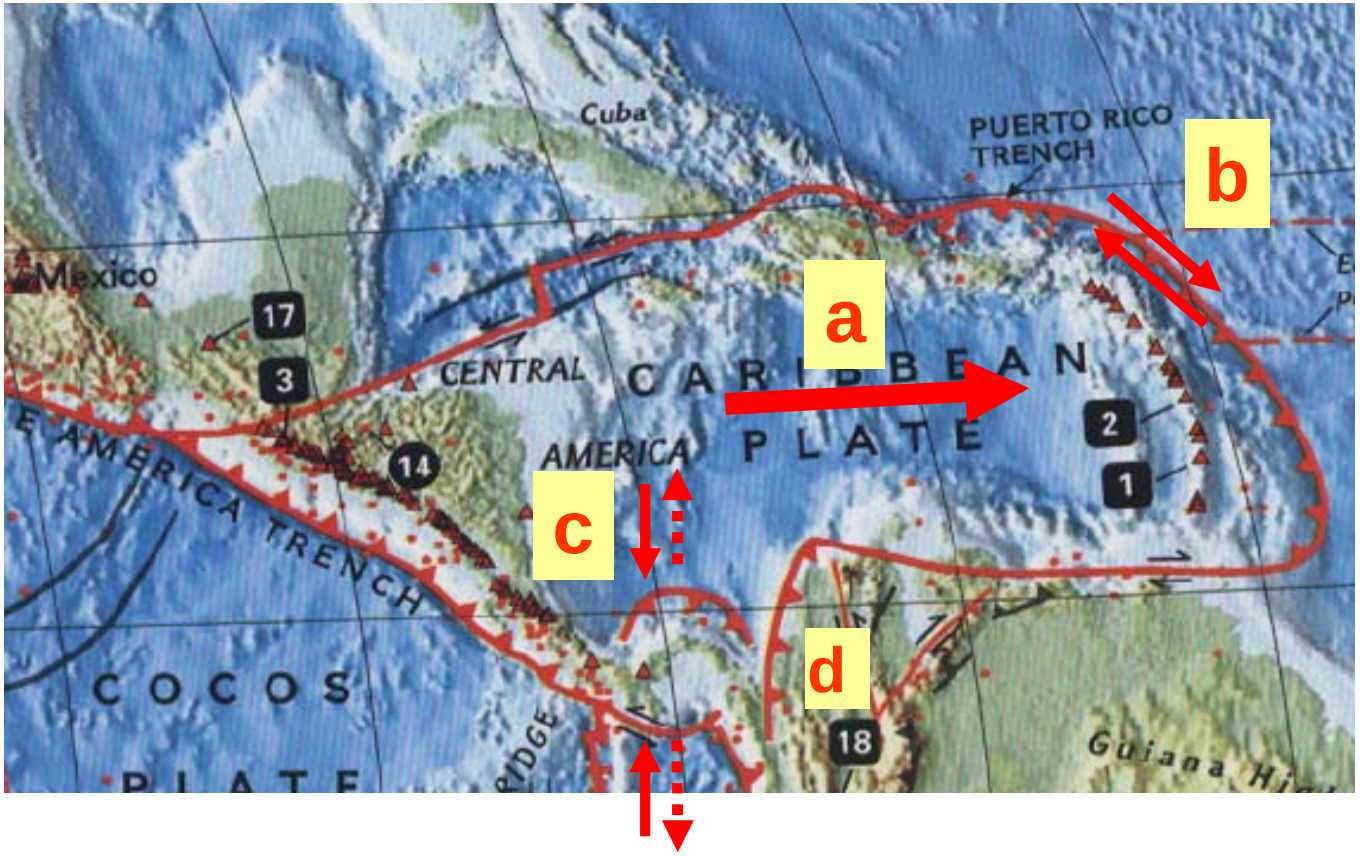
Look for different precursors in blocks, faults, and nodes



More untapped possibilities

Using satellite data to determine:

- Absolute displacement averaged over blocks
- Relative displacement averaged over faults
- Compression vs. tension (to discriminate locked and unlocked nodes)
- Heat flow, geochemistry and isotopes at the faults and nodes



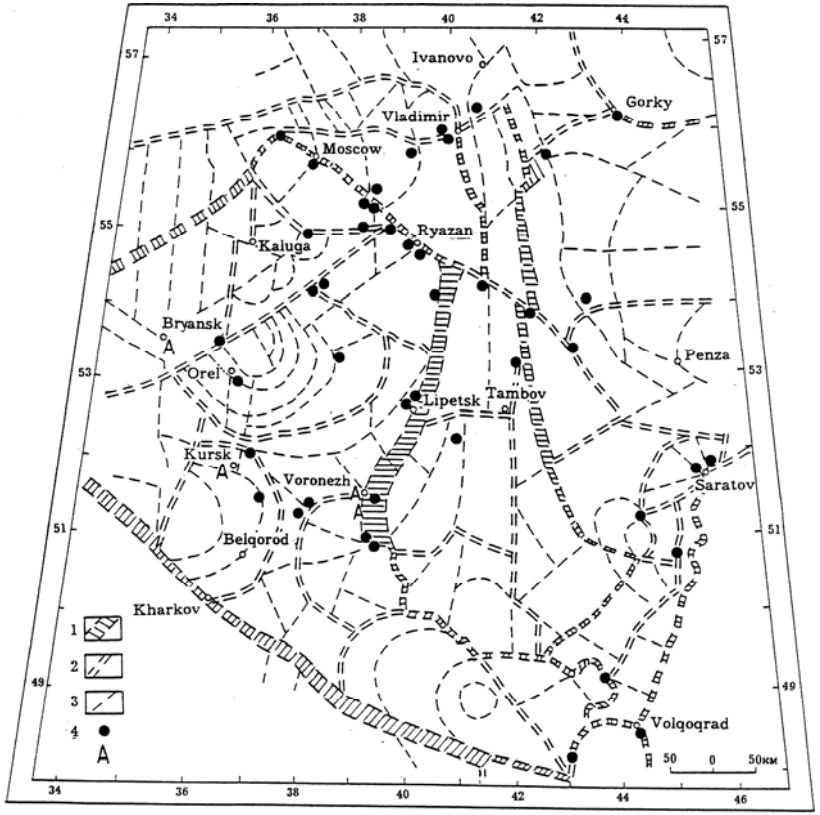
Fault networks in a platform: Russian plain

- **Study was prompted by collapse of a modern high quality building close to Moscow. In XVIII century a cathedral collapsed nearby.**
- **No possibility of usual suspects like landslide, karst, engineering, etc.**
- **As a last resort the fault network was reconstructed.**
- **Faults have been traced by usual suspects: Patterns of Holocene sediments, river terraces, topography; relief of crustal basement; and faults from Precambrian upwards, even if currently inactive.**

More untapped possibilities:

Platforms: *industrial accidents of unknown origin*

- Accidents are taken from the catalog of the Russian Ministry for Emergencies Management, 1989-1994
  - Accidents include breakdown of oil and gas pipelines; malfunction of railroads, collapse of buildings, oil and gas collectors, high risk depositories, etc.
- 80% of accidents happened within 25 km of an intersections/junctions of the faults, i.e. in the nodes.
- Implication: destructive slow movements (e.g. creep or slow earthquakes) also nucleate in the nodes
- The nodes of that territory have the same unfortunate feature: they harbor all 17 province capitals and all 3 nuclear power plants



Notations:

1-3 : *faults (lineaments)* of the 1st, 2D and 3D rank respectively; dotted lines indicate their vaguely expressed segments.

4 : industrial accidents of unknown origin

A: nuclear power plants

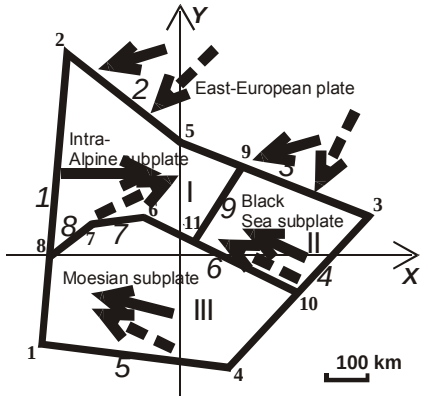
More untapped possibilities
Precursory perturbations in mantle flows

An example:
Reconstruction of driving forces from spatial distribution of seismicity: block model of Vrancea region.

Change of distribution signals destabilization.

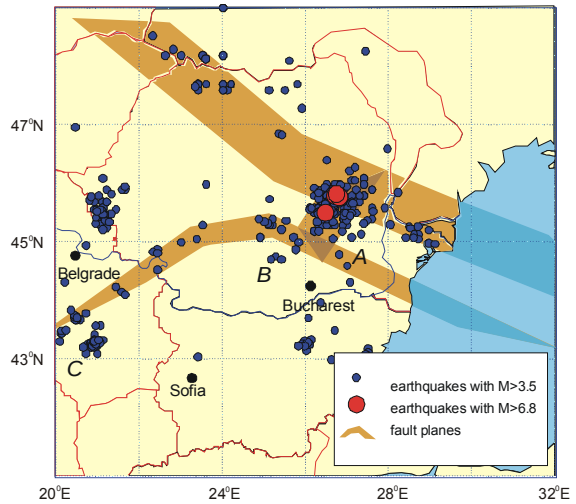
(Soloviev, Ismail-Zadeh, 2003.)

Geometry of the block system

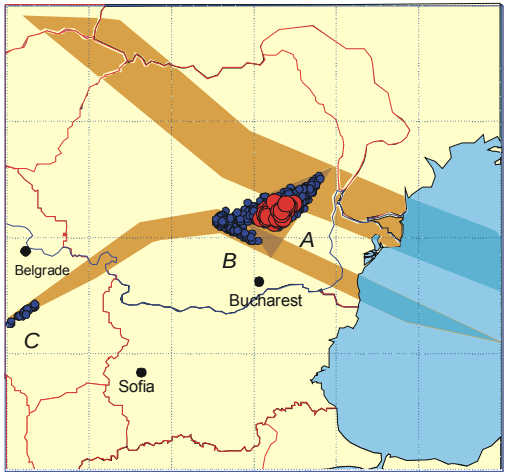


Arrows indicate driving forces: Solid ones correspond to synthetic seismicity on the left figure below, dashed ones correspond to synthetic seismicity on the right figure below

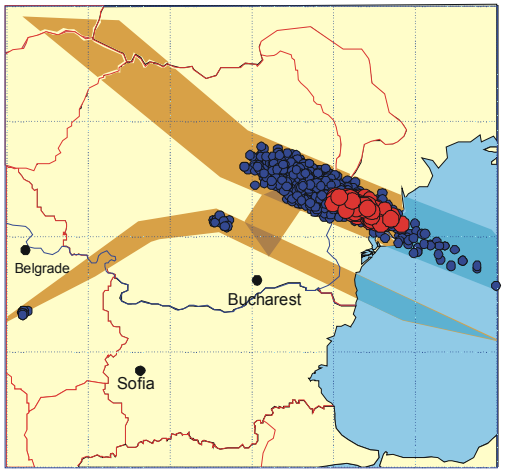
Observed seismicity, 1900-1995



Synthetic seismicity (solid arrows)



Synthetic seismicity (dashed arrows)



“The nation’s problems have become more numerous, more frequent, more severe, and in some cases more crisis related.”

-- F. Press

“Though this be madness, yet there is method in’t”

-- W. Shakespeare

“Of course, things are complicated…. But in the end every situation can be reduced a simple question: Do we act or not? If yes, in what way?”

-- E. Burdick