European Geosciences Union
General Assembly 2016
Vienna | Austria | 17 – 22 April 2016

NH4.4/SM3.7 Seismic Hazard and Disaster Risk: Assessment, Testing, and Implementation

Earthquake Hazard Assessment: Basics of Evaluation

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Seismic evidences accumulated to-date demonstrate clearly that most of the empirical relations commonly accepted in the early history of instrumental seismology can be proved erroneous when testing statistical significance is applied.

"What do we know about earthquakes?

Earthquakes are so complicated that we must apply some Statistics…"

Keiiti **Aki** (1930-2005)

Seismic hazard assessment (SHA) is not an easy task that implies a delicate application of statistics to data of limited size and different accuracy.

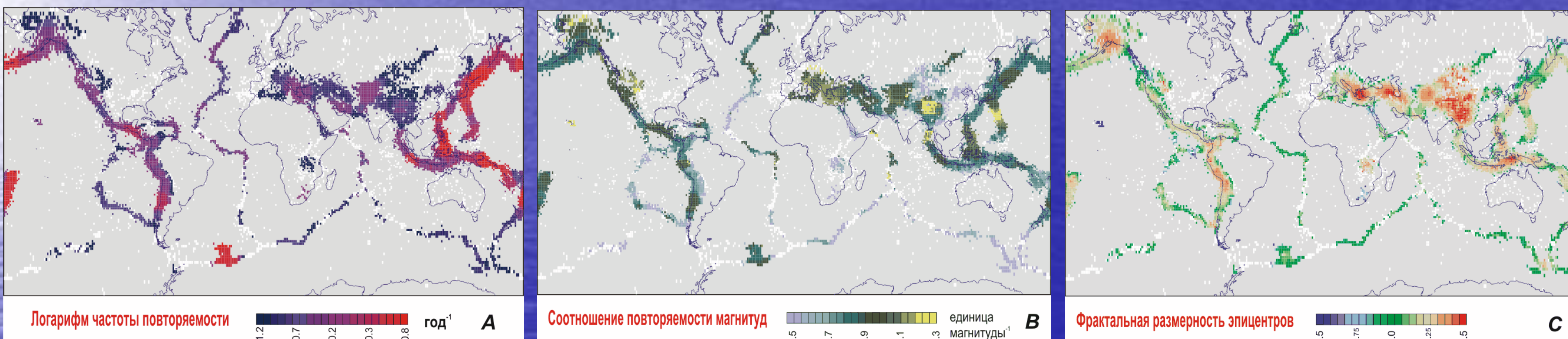
Earthquakes follow the Unified Scaling Law that generalizes the Gutenberg-Richter relationship by taking into account naturally fractal distribution of their sources. Moreover, earthquakes, including the great and mega events, are clustered in time and their sequences have irregular recurrence intervals.

Since the pioneering works of Keiiti Aki and M. A. Sadovsky

Okubo, P.G., K. Aki, 1987. Fractal geometry in the San Andreas Fault system. *J. Geophys. Res.*, **92** (B1), 345-356;
Садовский М.А. и др.б 1982. О свойстве дискретности горных пород. *Изв. АН СССР. Физика Земли*, № 12, 3-18;

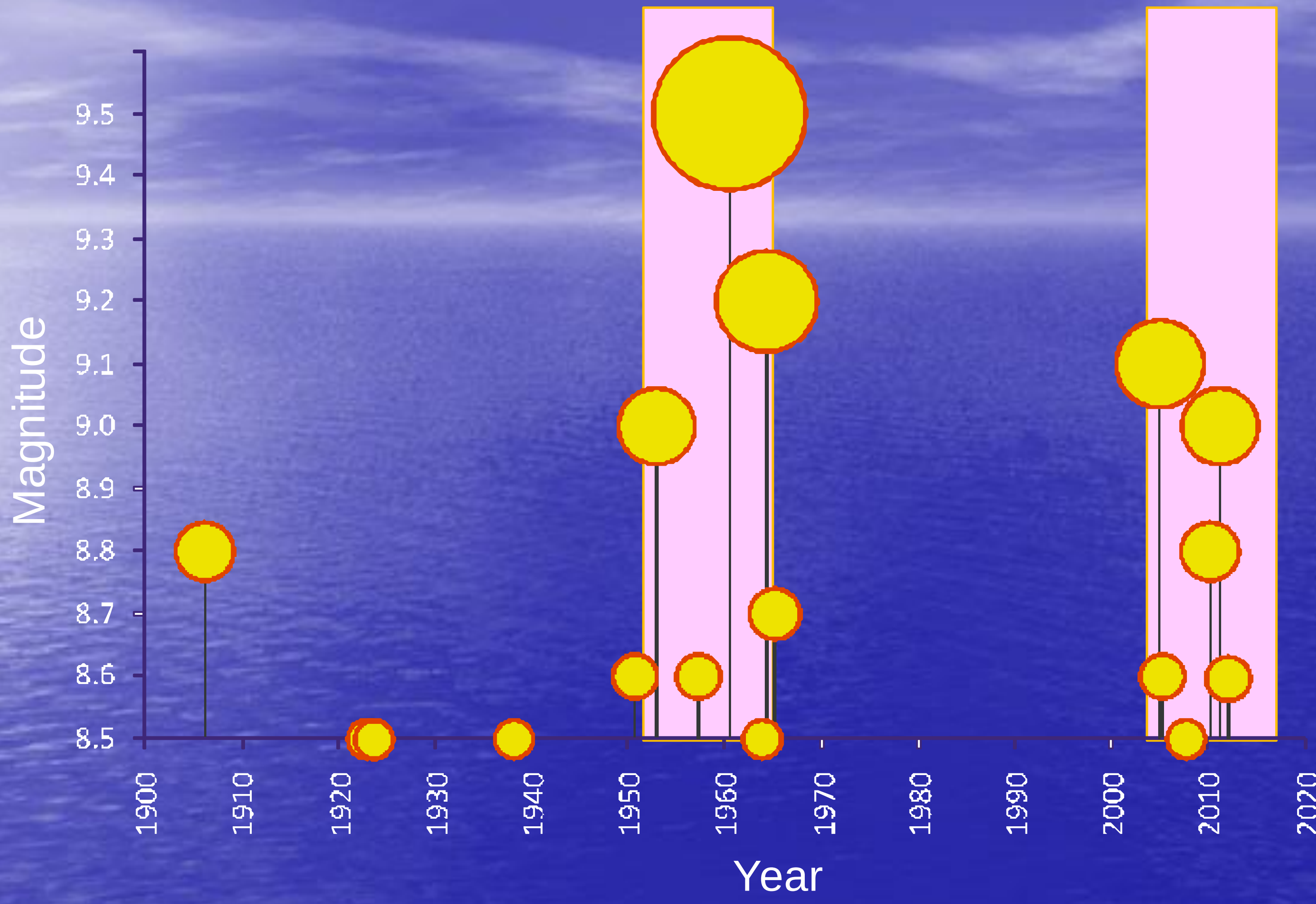
the understanding of the fractal nature of earthquakes and seismic processes keeps growing.

The Unified Scaling Law for Earthquakes that generalizes Gutenberg-Richter relation suggests -

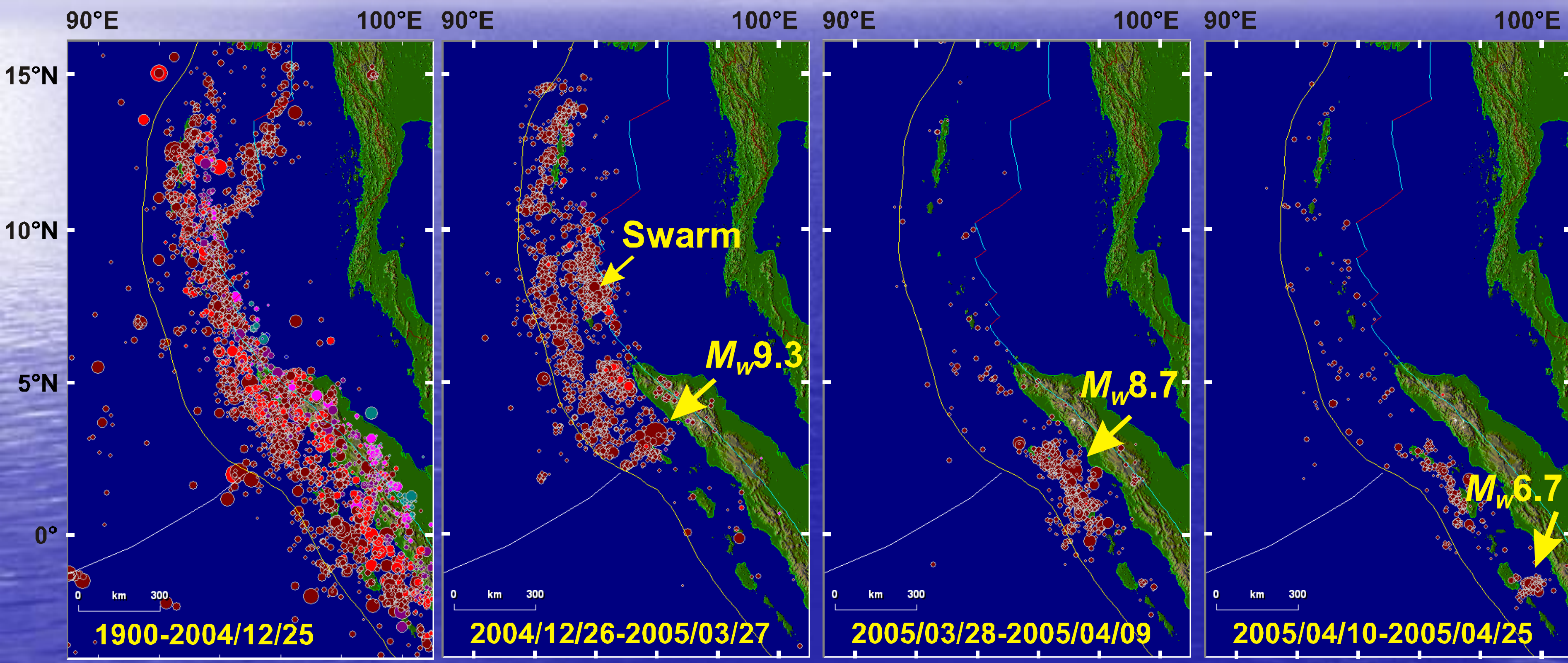


$$\log_{10}N = A + B\cdot(5 - M) + C\cdot\log_{10}L$$

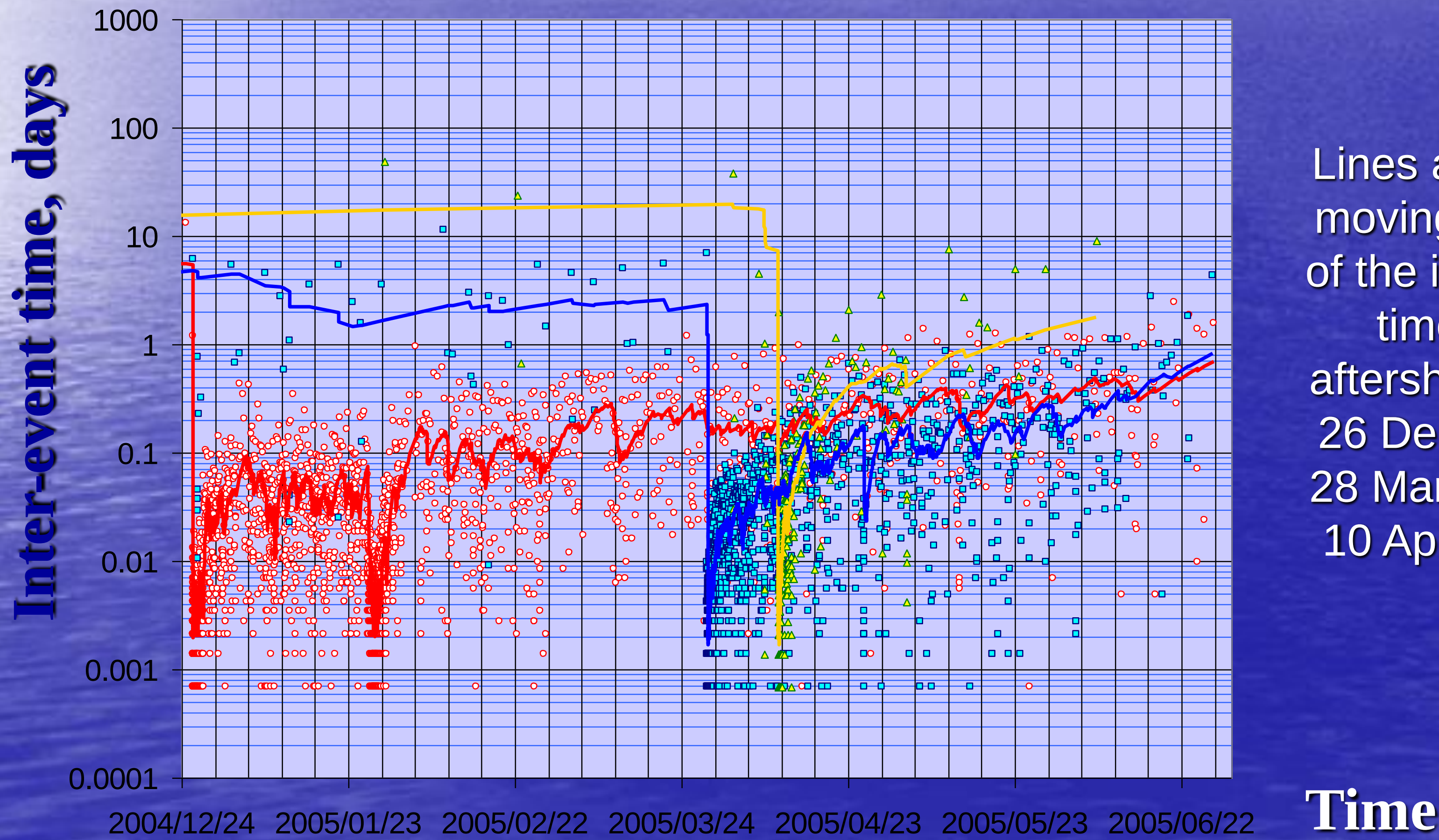
where N = N(M, L) is the expected annual number of earthquakes with magnitude M in an earthquake-prone area of linear dimension L.


Magnitude
9.5
9.4
9.3
9.2
9.1
9.0
8.9
8.8
8.7
8.6
8.5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Earthquake distribution in space is possibly fractal, definitely, far from uniform even in a single segment of a fault zone.



Earthquakes evidently cascade into aftershocks that re-adjust the hierarchical system of blocks-and-faults in the locality of the main shock rupture. The majority of the great earthquakes show switching to higher activity level of recurrence; their aftershock number differs by factor 100 or more and their relaxation time varies up to 50 times (Romashkova, L., V. Kossobokov, and D. Turcotte, Seismic cascades prior to and after recent largest earthquakes worldwide. *Eos Trans. AGU*, **81** (48), Fall Meet. Suppl., Abstract NG62C-09, 2000: F564-F565.).

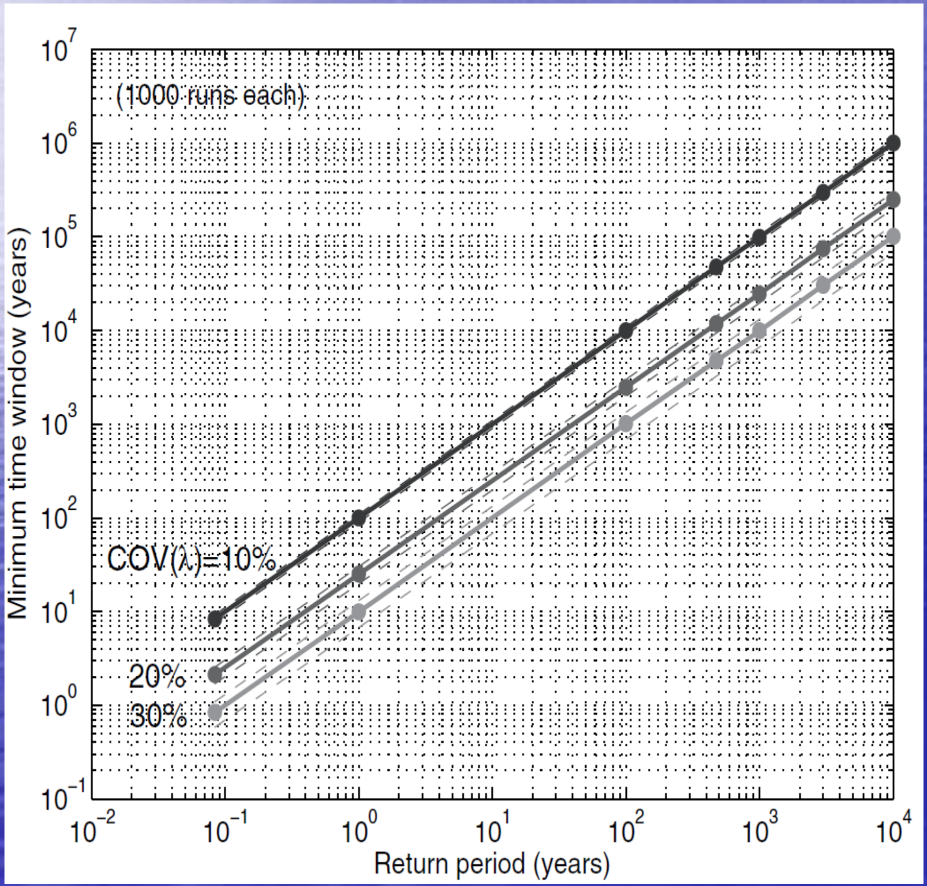


Lines are 20 per moving average of the inter-event time in an aftershock zone: 26 Dec 04 (red) 28 Mar 05 (blue) 10 Apr 05 (yellow)

Furthermore, earthquake related observations are limited to the recent most decades (or centuries in just a few rare cases).

Evidently, all this complicates reliable assessment of seismic hazard and associated risks. Making SHA claims, either termless or time dependent (so-called t-DASH), quantitatively probabilistic in the frames of the most popular objectivists' viewpoint on probability requires a long series of "yes/no" trials, which cannot be obtained without an extended rigorous testing of the method predictions against real observations.

Minimum time windows required for ensuring a given uncertainty level on the estimated rate λ, COV(λ), versus return period, 1/λ.



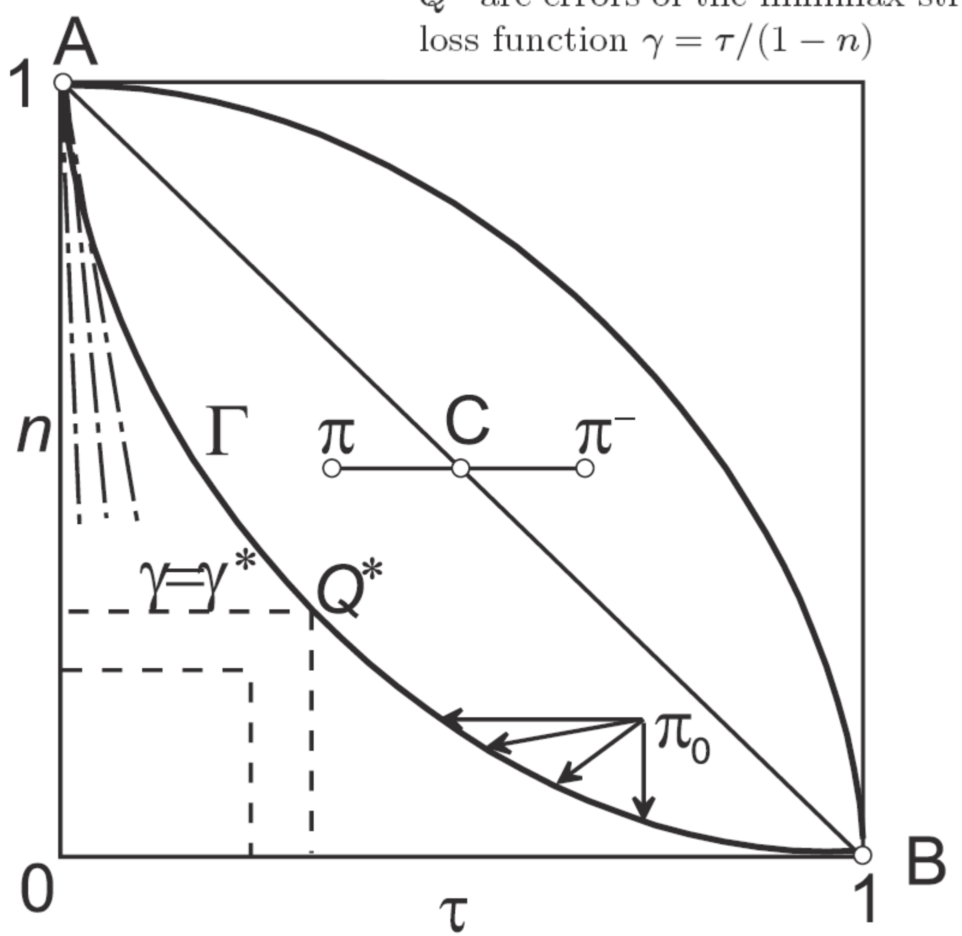
Getting, experimentally, reasonable confidence limits on an objective estimate of recurrence rate of an earthquake requires a geologic span of time which is unreachable for instrumental, or even historical, seismology (see, e.g., ***Beauval et al., 2008*****). That is why probability estimates in Probabilistic Seismic Hazard Analysis remain subjective values from 0 to 1, derived from analytically tractable hypothetical models of seismicity.**

Therefore, we reiterate the necessity and possibility of applying the modified tools of Earthquake Prediction Strategies.

In particular,

- the Error Diagram, introduced by G.M. Molchan in early 1990ies for evaluation of SHA, and
- the Seismic Roulette null-hypothesis as a measure of the alerted space.

Fig. 5.1. Error set $\mathcal{E}(J)$ for prediction strategies based on a fixed type of information J. Point A corresponds to an optimistic strategy, point B to a pessimistic strategy, and the interval AB corresponds to strategies of random guess. C is the center of symmetry of $\mathcal{E}(J)$. π and π^- are a strategy and its antipodal strategy. Γ is the error diagram of optimal strategies. *Arrows* indicate a better forecast relative to the strategy π_0. *Dashed lines* are contours of the loss function $\gamma = \max(n, \tau)$. Q^* are errors of the minimax strategy, $n = \tau$. *Dash-dotted* lines are contours of the loss function $\gamma = \tau/(1-n)$



Error diagram

Molchan, G.M. Earthquake Prediction as Decision-making Problem. Pure Appl. Geoph, **149**, 233-247, 1997.

Molchan, G.M. 5. Earthquake Prediction Strategies: a theoretical analysis. In: Keilis-Borok, V.I., and A.A. Soloviev, (Editors). *Nonlinear Dynamics of the Lithosphere and Earthquake Prediction*. Springer, Heidelberg, 208-237, 2003.

Seismic Roulette Null-Hypothesis

Consider a roulette wheel with as many sectors as the number of events in a sample catalog of earthquakes, a sector per event.

- Make your bet according to prediction: determine, which events are inside area of alarm, and put one chip in each of the corresponding sectors.
- Nature turns the wheel.
- If seismic roulette is not perfect…

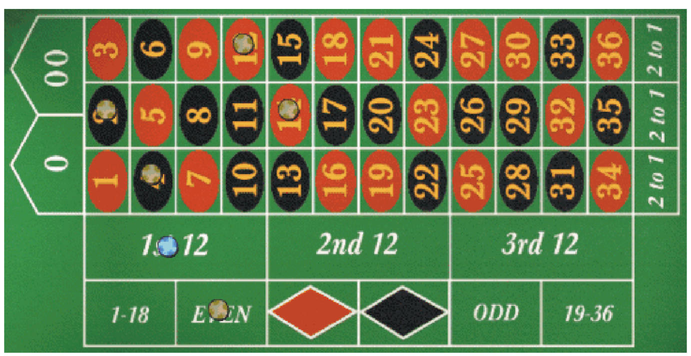
then ***systematically*** you can win! ☺

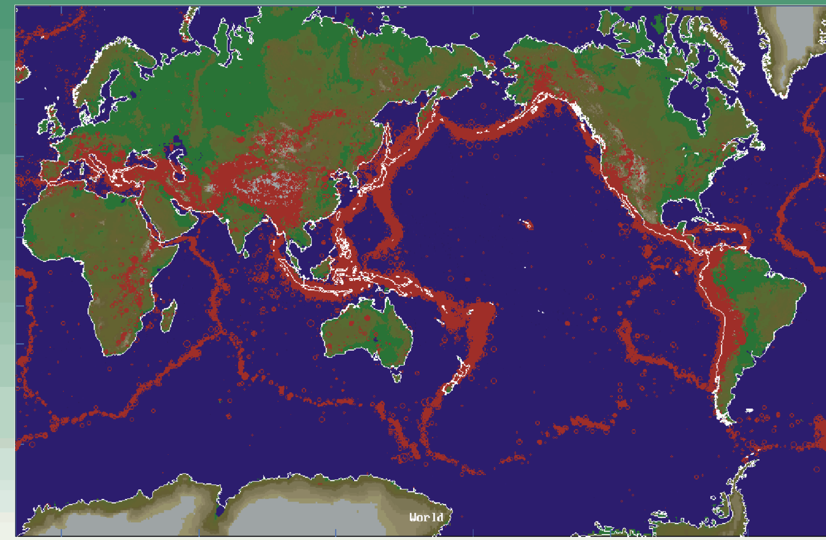
or lose … ☹

If you are smart enough to know "antipodal strategy" (Molchan, 1994; 2003), make the predictions efficient ------

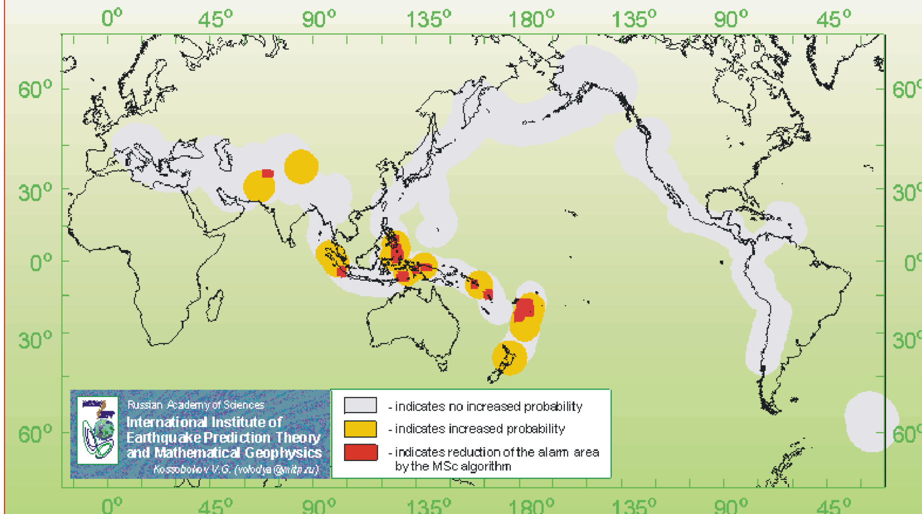
and your wins will outscore the losses! ☺ ☺ ☹ ☺ ☺ ☺ ☹ ☺ ☺ ☺

Seismic Roulette





Regions of Increased Probability of Magnitude 8.0+ Earthquakes
as on July 1, 2000 (*subject to update on January 1, 2001*)



The set of errors, i.e. the rates of failure and of the alerted space-time volume, compared to those obtained in the same number of random guess trials permits evaluating the SHA method effectiveness and determining the optimal choice of the parameters in regard to specified cost-benefit functions. These and other information obtained in such a testing supplies us with a realistic estimate of confidence in SHA results and related recommendations on the level of risks for decision making in regard to engineering design, insurance, and emergency management.

Such a situation contradicts generally accepted assumptions for analytically tractable or computer simulations and complicates design of reliable methodologies for realistic hazard assessment, as well as search and definition of precursory behaviors to be used for forecast/prediction purposes.

Regrettably, many branches of Natural Sciences today appear to belong to the "Pre-conceptual Sciences," as defined and elaborated by Danae Pyle (a pre-adolescent girl with a pessimistic view of the world) to Lucy (a talking pygmy Clydesdale) in a series of the famous "Non Sequitur" comics by Wiley Miller.

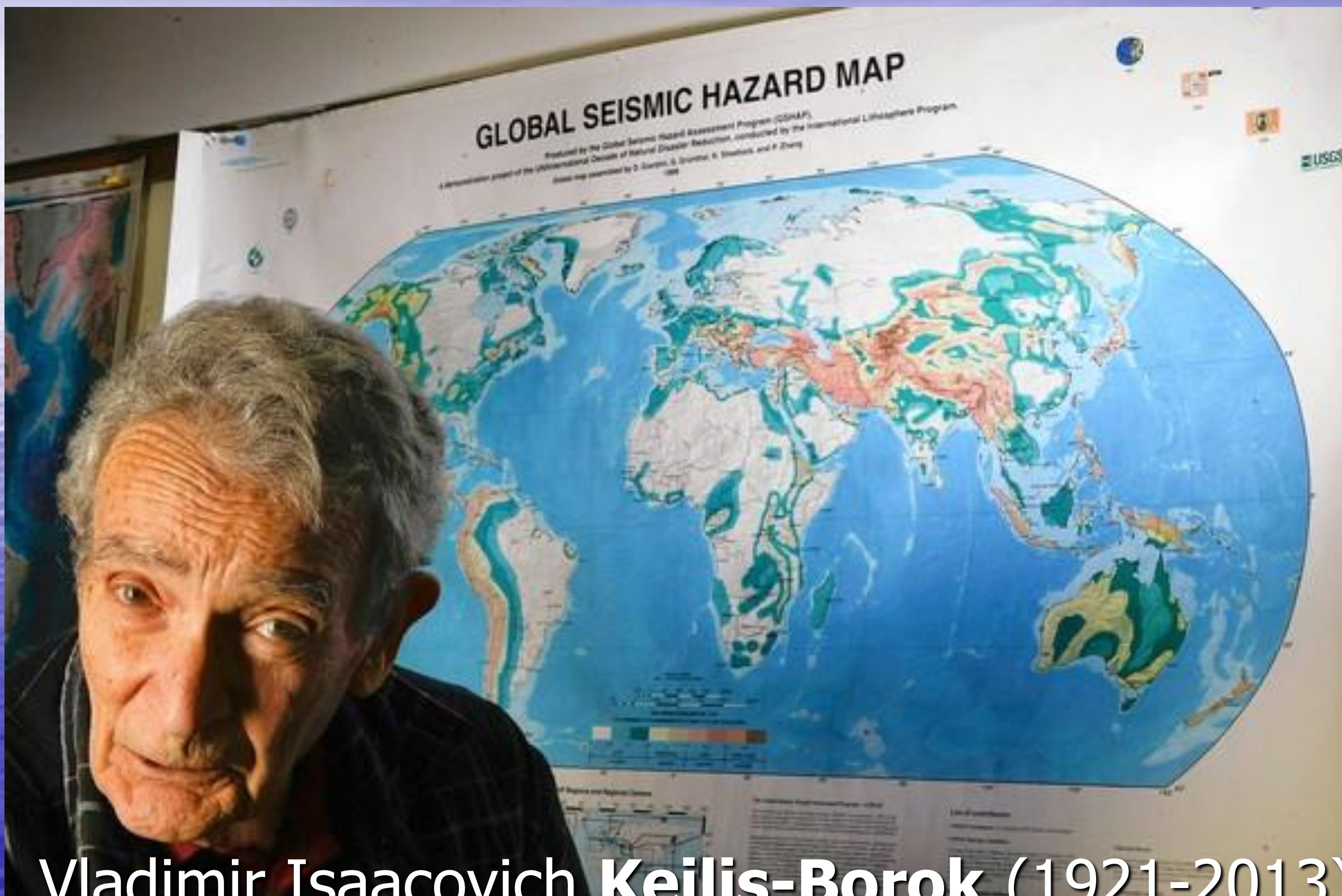
As a result, the conclusions drawn from such simulations and analyses can MISLEAD TO SCIENTIFICALLY GROUNDLESS APPLICATION, which is unwise and extremely dangerous in assessing expected societal risks and losses.

Concluding the series dated June 06, 08, and 10, 2005, Danae answers with… "**That's where you come in**…" when asked by Lucy how she is going to float across the ravine and dismiss "an unproven theory" of gravity.

SCIENCE SHOULD BE ABLE TO WARN PEOPLE OF LOOMING DISASTER, Vladimir Keilis-Borok believed.

"My main trouble," he says, "is feeling of responsibility."

(*Los Angeles Times*, 9 July 2012)



Vladimir Isaacovich **Keilis-Borok** (1921-2013)

The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR). The GSHAP project terminated in 1999 .

"One is well advised, when traveling to a new territory, to take a good map and then to check the map with the actual territory during the journey" [Wasserburg, 2010].

A systematic comparison of the GSHAP peak ground acceleration estimates with those related to actual strong earthquakes, unfortunately, discloses gross inadequacy of this "probabilistic" product, which appears UNACCEPTABLE FOR ANY KIND OF RESPONSIBLE SEISMIC RISK EVALUATION AND KNOWLEDGEABLE DISASTER PREVENTION.

Each of 1181 strong crustal earthquakes in 2000-2009 has from 6 to 58 values of GSHAP PGA in the ¼° × (1/4cosϕ)° cell centered at its epicenter (ϕ, λ).

The transformed values the GSHAP expected maximum, I_0(mPGA), and the estimate of observed value, I_0(M), allow to count the number of "surprises", the average difference ΔI_0, and the median of ΔI_0 for earthquakes of different magnitude.

For example, each of the 59 magnitude 7.5 or larger earthquakes in 2000-2009 was a "surprise" for GSHAP Seismic Hazard Map; moreover, the minimum of the 59 values of ΔI_0 is 0.6.

The average and the median of ΔI_0 are about 2.

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Kossobokov V., Peresan A., Panza G.F. (2015)
REALITY CHECK: SEISMIC HAZARD MODELS YOU CAN TRUST. EOS 96(13): 9-11

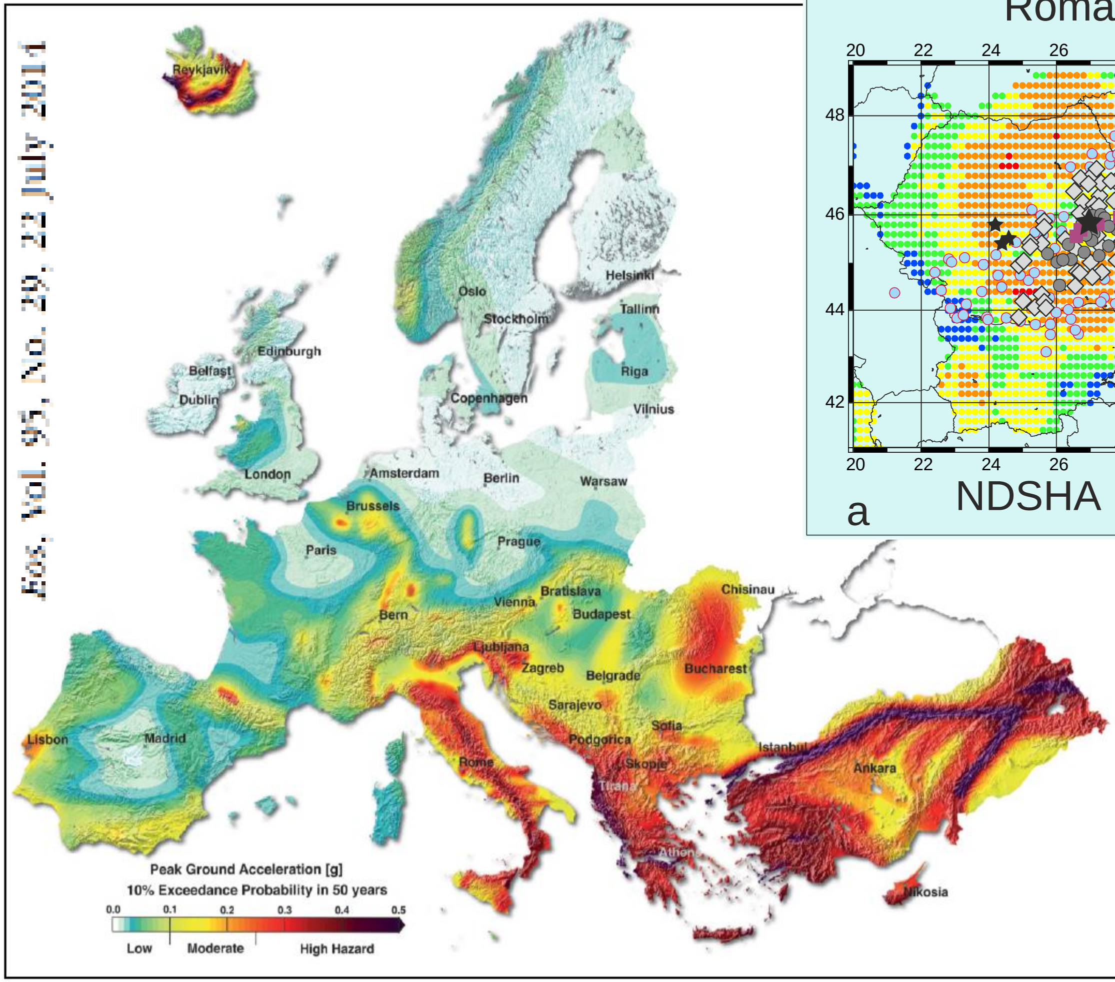
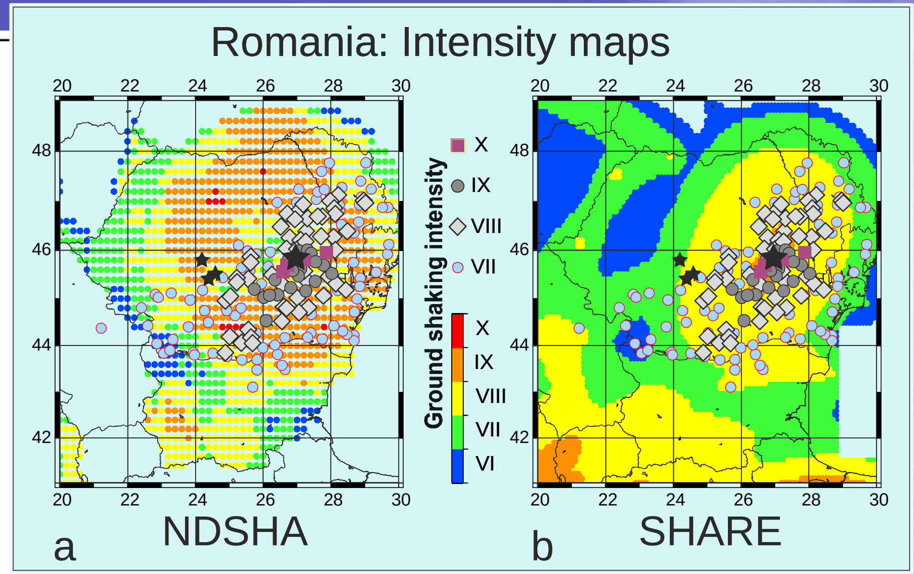
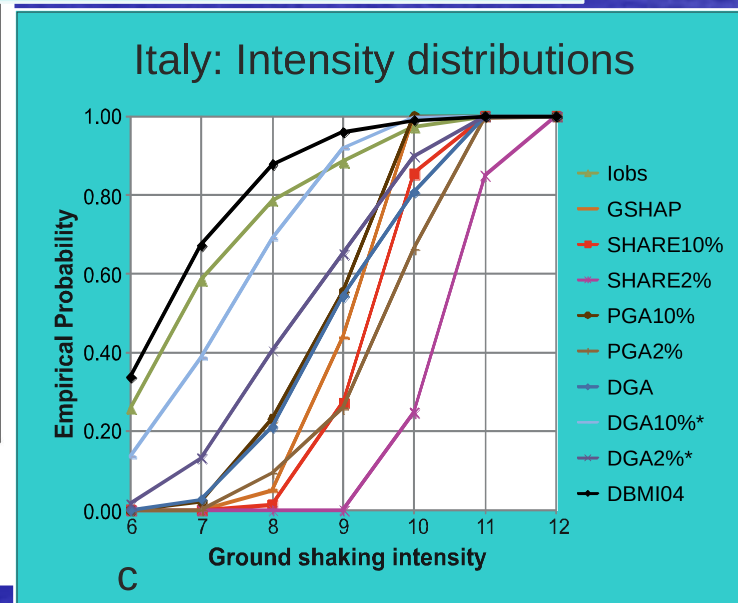


Fig. 1. European Seismic Hazard Map (ESHM13) displaying the 10% exceedance probability in 50 years for peak ground acceleration (PGA) in units of gravity (g). Cold colors indicate comparatively low hazard areas (PGA ≤ 0.1g), yellow and orange indicate moderate-hazard values (0.1g < PGA ≤ 0.25g), and red colors indicate high-hazard areas (PGA ≥ 0.25g).





Chapter 12

Why are the Standard Probabilistic Methods of Estimating Seismic Hazard and Risks Too Often Wrong

Giuliano Panza[1,2,3,6], Vladimir G. Kossobokov[2,4,5,6], Antonella Peresan[1,2,6] and Anastasia Nekrasova[2,4]

[1] Department of Geosciences, University of Trieste, Trieste, Italy, [2] The Abdus Salam International Centre for Theoretical Physics – SAND Group, Trieste, Italy, [3] China Earthquake Administration, Institute of Geophysics, Beijing, China, [4] Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russian Federation, [5] Institut de Physique du Globe de Paris, France, [6] International Seismic Safety Organization, ISSO

Ne quid falsi dicere audeat, ne quid veri non audeat

De oratore II, 15, 62 (Cic)

ABSTRACT

According to the probabilistic seismic hazard analysis (PSHA) approach, the deterministically evaluated or historically defined largest credible earthquakes (often referred to as Maximum Credible Earthquakes, MCEs) are "an unconvincing possibility" and are treated as "likely impossibilities" within individual seismic zones. However, globally over the last decade such events keep occurring where PSHA predicted seismic hazard to be low. Systematic comparison of the observed ground shaking with the expected one reported by the Global Seismic Hazard Assessment Program (GSHAP) maps discloses gross underestimation worldwide. Several inconsistencies with available observation are found also for national scale PSHA maps (including Italy), developed using updated data sets. As a result, the expected numbers of fatalities in recent disastrous earthquakes have been underestimated by these maps by approximately two to three orders of magnitude. The total death toll in 2000–2011 (which exceeds 700,000 people, including tsunami victims) calls for a critical reappraisal of GSHAP results, as well as of the underlying methods.

In this chapter, we discuss the limits in the formulation and use of PSHA, addressing some theoretical and practical issues of seismic hazard assessment, which range from the overly simplified assumption that one could reduce the tensor problem of seismic-wave generation and propagation into a scalar problem (as implied by ground motion

Earthquake Hazard, Risk, and Disasters. http://dx.doi.org/10.1016/B978-0-12-394848-9.00012-2
 309

A simple answer exists to the question in the title of this chapter: most, if not all, the standard probabilistic methods to assess seismic hazard, namely PSHA, and associated risks are based on subjective, commonly unrealistic, and even erroneous assumptions about seismic recurrence. After years with many publications, we know that recurrent earthquake hazard results have failed us.

"Predicting earthquakes is as easy as one-two-three.

- Step 1: Deploy your precursor detection instruments at the site of the coming earthquake.
- Step 2: Detect and recognize the precursors.
- Step 3: Get all your colleagues to agree and then publicly predict the earthquake through approved channels."

Scholz, C.H., 1997. Whatever happened to earthquake prediction. *Geotimes*, **42**(3), 16-19

General Definition of *Earthquake Prediction*

The United States National Research Council, Panel on Earthquake Prediction of the Committee on Seismology suggested the following definition (1976, p.7):

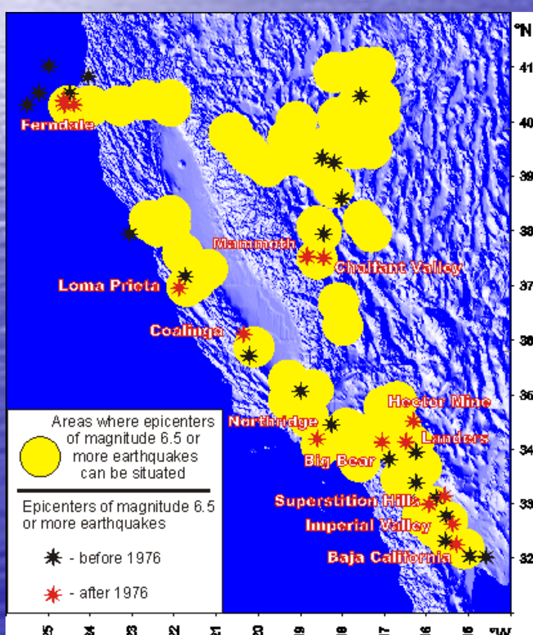
"An earthquake prediction must specify the expected magnitude range, the geographical area within which it will occur, and the time interval within which it will happen with sufficient precision so that the ultimate success or failure of the prediction can readily be judged. Only by careful recording and analysis of failures as well as successes can the eventual success of the total effort be evaluated and future directions charted. Moreover, scientists should also assign a confidence level to each prediction."

So far,

- none of the proposed earthquake precursory signals evaluated by the International Association for Seismology and Physics of the Earth's Interior showed sufficient evidence to be used as a precursor (Wyss and Booth, 1997) and
- none of the gridded rate-based forecast models passed the rigid testing by Collaboratory for the Study of Earthquake Predictability (CSEP; http://www.cseptesting.org/; Jordan, 2006; Schorlemmer and Gerstenberger, 2014).

NATURAL SCALING OF TIME

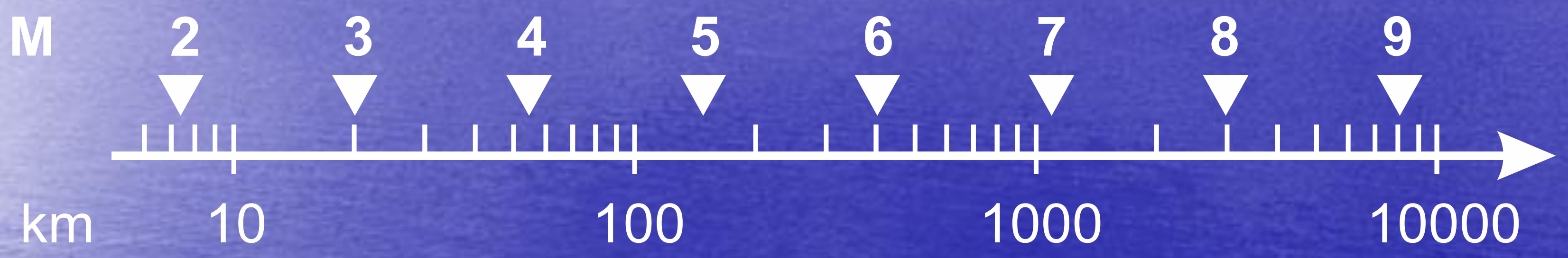
Usually, earthquake prediction is classified in respect to duration of expectation time while overlooking term-less identification of earthquake prone areas, as well as the spatial accuracy of an earthquake prediction method. N



- The 73 D-intersections of morphostructural lineaments in California and Nevada determined by *Gelfand et al.* (1976) as earthquake-prone for magnitude 6.5+ events. Since 1976 fifteen magnitude 6.5+ earthquakes occurred, all in a narrow vicinity of the D-intersections

Natural Scaling of Size

The linear dimensions of the target earthquake preparation zone of $R = 10^{0.43\,M}$ km (*Dobrovolsky et al., 1979*) and are independently confirmed by *Bowman et al.* (*1998*), who claimed $\log_{10}R \sim 0.44$ M. [$\log_{10}e = 0.434\ldots$]

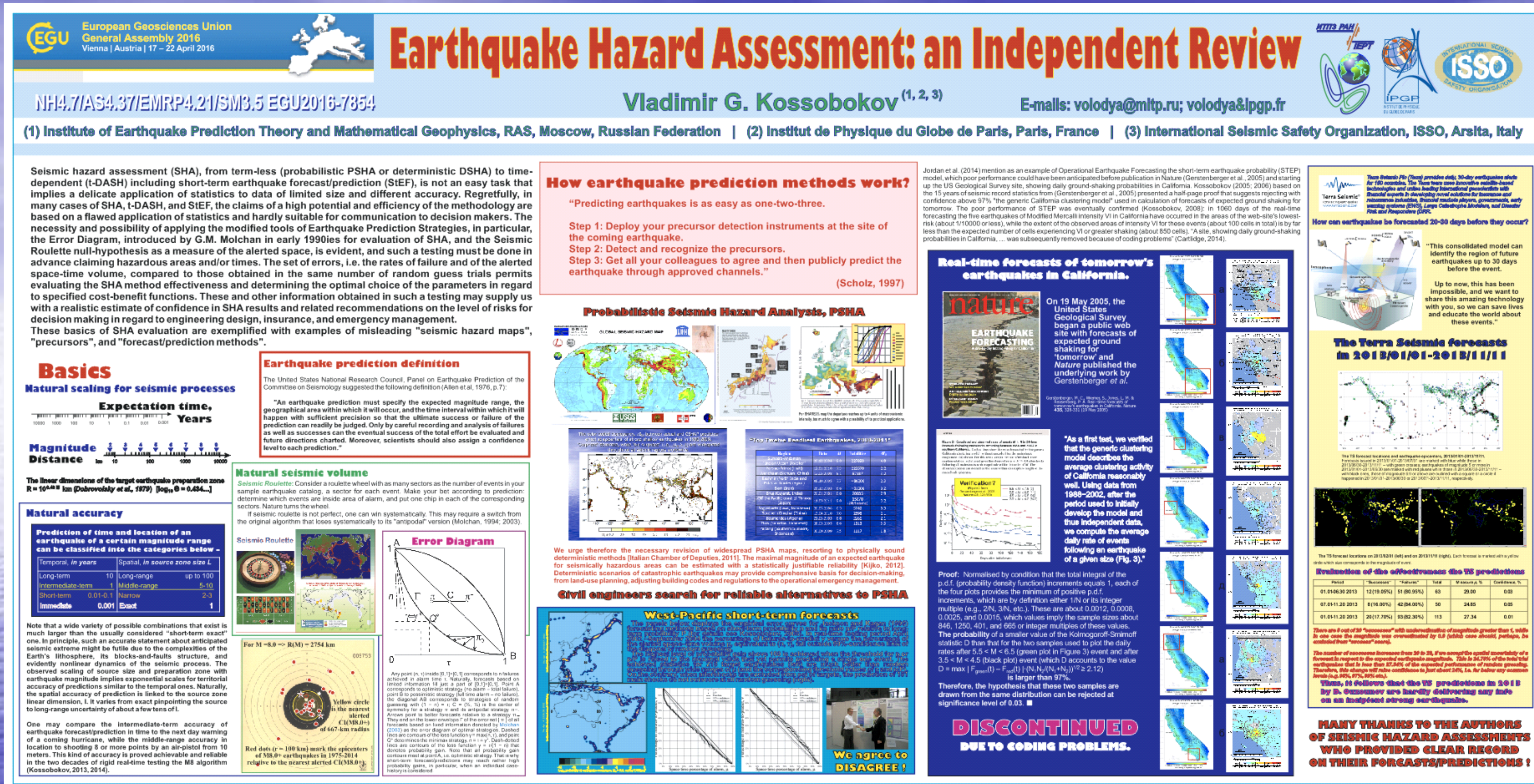


The forecasts are often made for a "cell" (Schorlemmer et al., 2010; Lee et al., 2011) or "seismic region" (McCann et al., 1979; Kagan and Jackson, 1991, 1995) whose area is not linked to the size of the target earthquake. This might be another source for making a wrong choice in parameterization of a forecast / prediction method and, eventually, for unsatisfactory performance in real-time applications.

Natural Accuracy

Prediction of time and location of an earthquake of a certain magnitude range can be classified into the categories listed in the following Table –

Temporal, ***in years***		Spatial, ***in source zone size L***	
Long-term	10	Long-range	up to 100
Intermediate-term	1	Middle-range	5-10
Short-term	0.01-0.1	Narrow	2-3
Immediate	0.001	Exact	1



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D.110 EGU2016-17535 Neo-Deterministic and Probabilistic Seismic Hazard Assessments: a Comparative Analysis by Antonella Peresan, Andrea Magrin, Anastasia Nekrasova, Vladimir Kossobokov, and Giuliano F. Panza

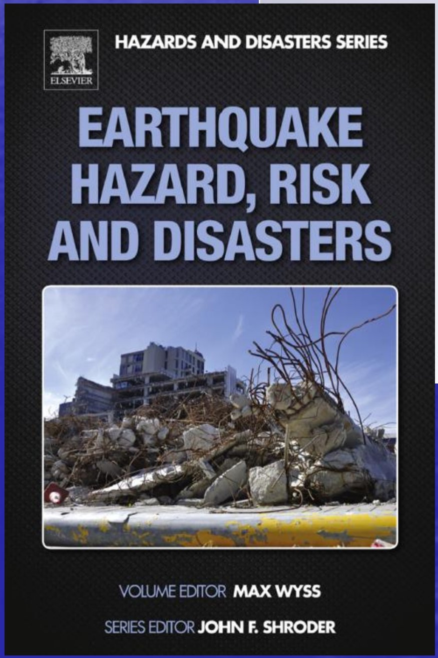
D.122 EGU2016-17706 The Unified Scaling Law for Earthquakes in the Friuli Venezia Giulia Region by Anastasia Nekrasova, Antonella Peresan,Andrea Magrin, and Vladimir Kossobokov

D.127 EGU2016-7794 Earthquake Hazard and Risk Assessment based on Unified Scaling Law for Earthquakes: State of Gujarat, India byAnastasia Nekrasova, Vladimir Kossobokov, and Imtiyaz Parvez

Understanding the complexity of non-linear dynamics of hierarchically organized systems of blocks-and-faults has led already to methodologies of neo-deterministic seismic hazard analysis and intermediate-term middle- to narrow-range earthquake prediction algorithms tested in real-time applications over the last decades.

The results of this truly global 20-year old experiment are indirect confirmations of the existing common features of both the predictability and the diverse behavior of the Earth's naturally fractal lithosphere.

The statistics achieved to date prove (with confidence above 99%) rather high efficiency of the M8 and M8-MSc predictions limited to intermediate-term middle- and narrow-range accuracy.



Kossobokov V (2014) Chapter 18. Times of Increased probabilities for occurrence of catastrophic earthquakes: 25 years of hypothesis testing in real time. In: Wyss M, Shroder J (eds) *Earthquake Hazard, Risk, and Disasters*. Elsevier, London, 477-504.

Kossobokov, VG (2012) Earthquake prediction: 20 years of global experiment. *Natural Hazards*; DOI 10.1007/s11069-012-0198-1

Real-time prediction of the world largest earthquakes: An experiment started in 1992 with a publication of

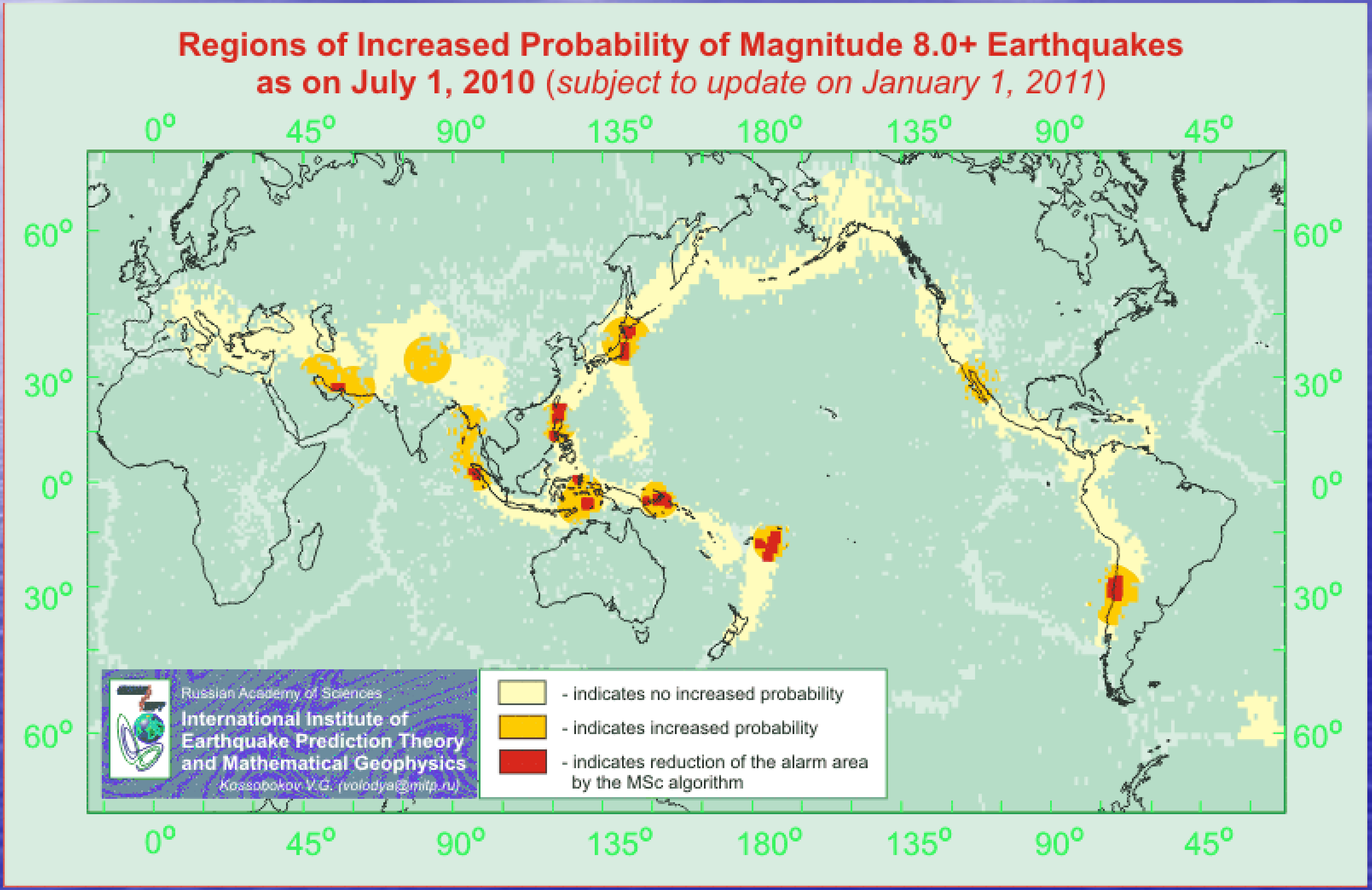
[Healy, J. H., V. G. Kossobokov, and J. W. Dewey. A test to evaluate the earthquake prediction algorithm, M8, *U.S. Geol. Surv. Open-File Report* **92-401**, 23 p. with 6 Appendices, 1992]

is going on.

Although the M8-MSc predictions are intermediate-term middle-range and by no means imply any "red alert", some colleagues have expressed a legitimate concern about maintaining necessary confidentiality. Therefore, the up-to-date predictions are not easily accessed, although available on the password-protected web-pages

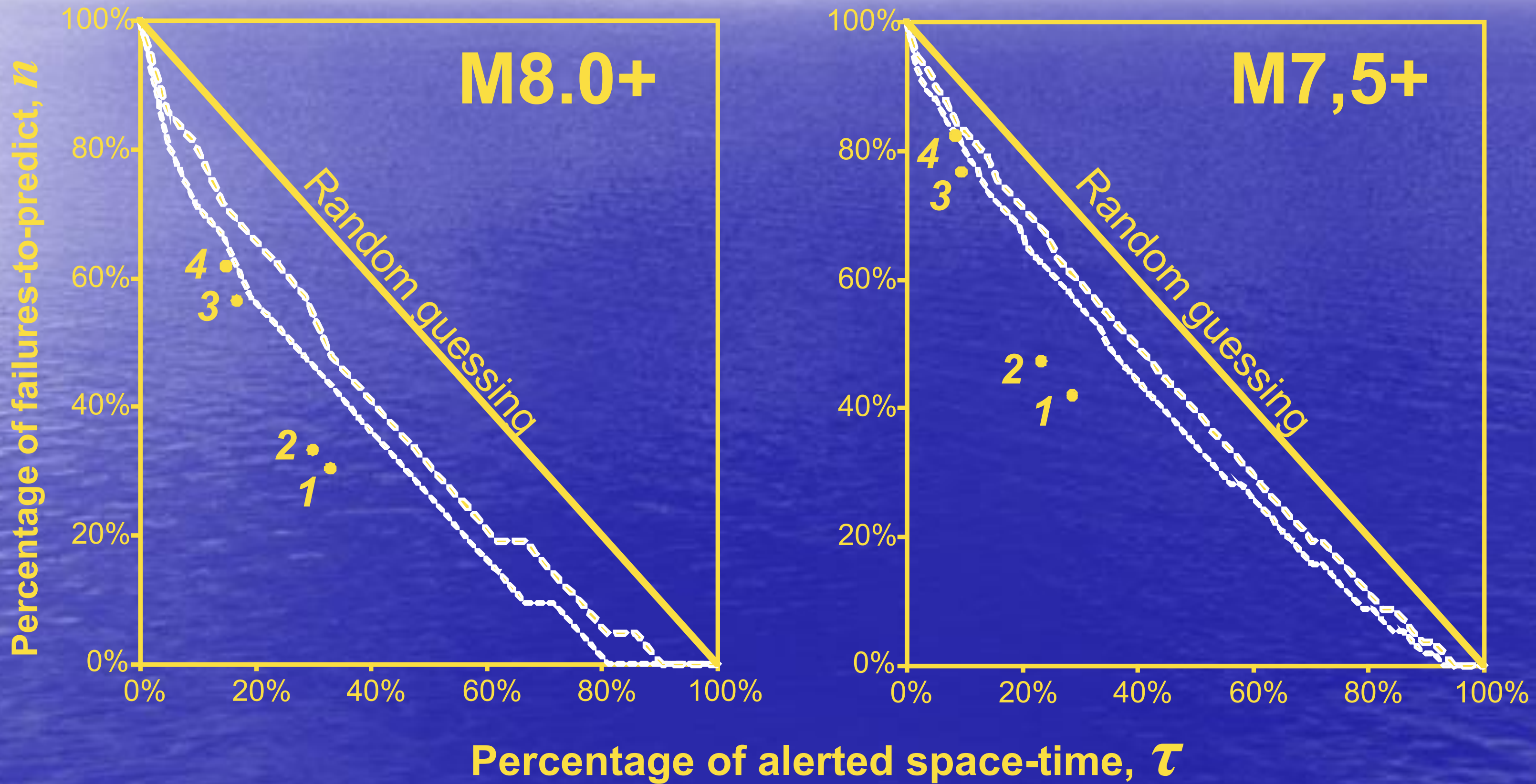
to about 150 Test Observers.

Real-time prediction of the world largest earthquakes
(http://www.mitp.ru)



Error Diagrams for the results of the Global Test of the M8-MSc predictions of the great (M8.0+) and significant (M7.5+):

M8, 1985–2013 (1); 1992–2013 (2); M8–MSc, 1985–2013 (3), and 1992–2013 (4). The "random guessing" is outlined with the 95 and 99% confidence level curves (for 21 and 57 independent tests on the left and right).



Kossobokov V, Soloviev A (2015). Evaluating the Results of Testing Algorithms for Prediction of Earthquakes. *Doklady Earth Sciences, 2015, Vol. 460, Part 2, pp. 192–194*

Conclusions – The Four Paradigms

Statistical validity of predictions demonstrated in more than two decades of rigorous testing confirms the underlying paradigms:

- Seismic premonitory patterns exist;
- Formation of earthquake precursors at scale of years involves large size fault system;
- The phenomena are similar in a wide range of tectonic environment…
- … and in other complex non-linear systems

(e.g., Keilis-Borok, Gabrielov, and Soloviev, 2009;
Keilis-Borok,Soloviev, and Lichtman, 2009).

Conclusion : Seismic Roulette is not perfect

Are these predictions useful?

- Yes, if used in a knowledgeable way.
- Their accuracy is already enough for undertaking earthquake preparedness measures, which would prevent a considerable part of damage and human loss, although far from the total.
- The methodology linking prediction with disaster management strategies does exist.

The earthquake detection could have been utilized to implement measures and improve earthquake preparedness in advance; unfortunately this was not done, in part due to the predictions' limited distribution and the lack of applying existing methods for using intermediate-term predictions to make decisions for taking action.

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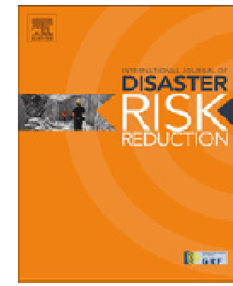

Advance prediction of the March 11, 2011 Great East Japan Earthquake: A missed opportunity for disaster preparedness

C. Davis [a,*], V. Keilis-Borok [b,c], V. Kossobokov [c,d], A. Soloviev [c]

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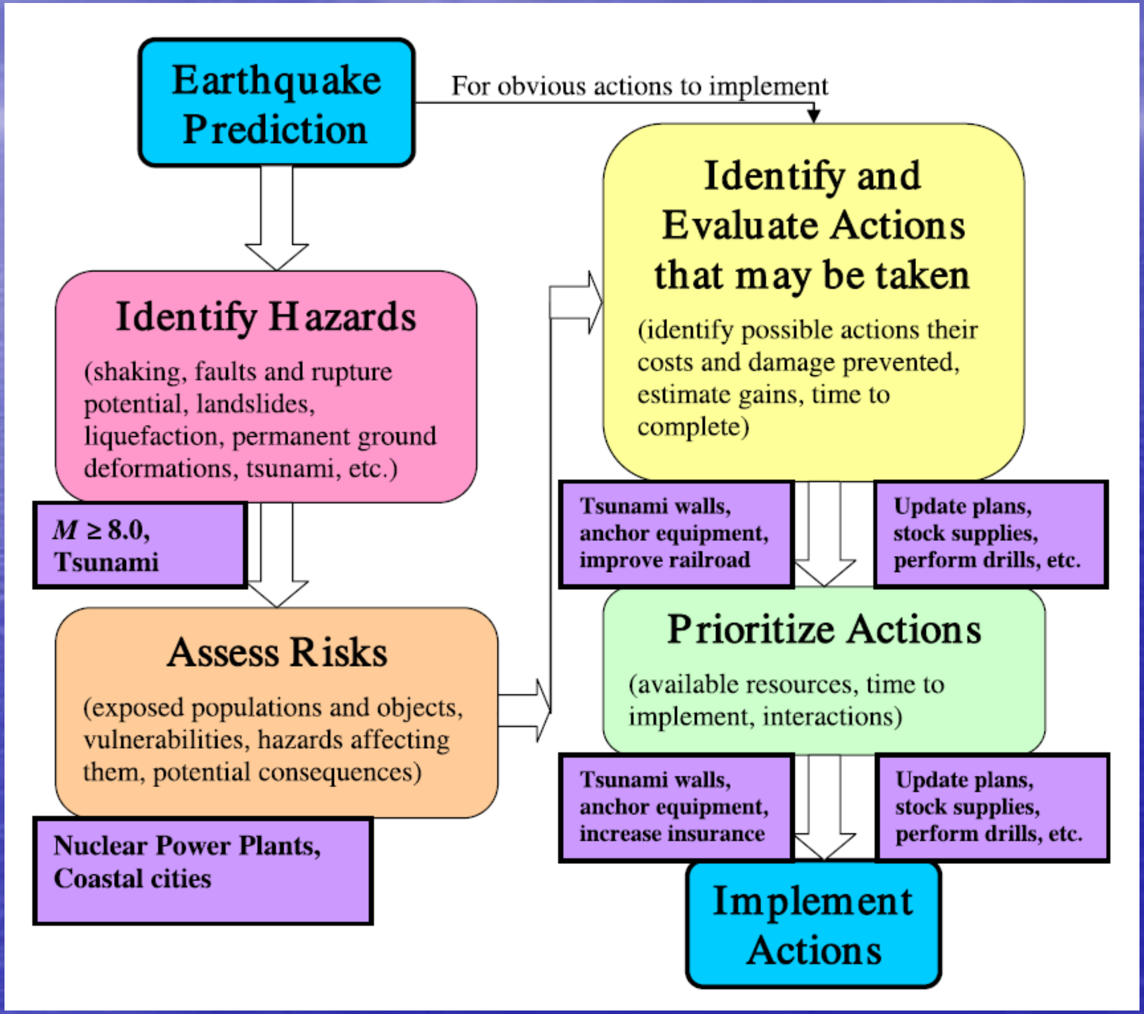
[b] Department of Earth and Planetary Sciences and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA
[c] Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, 84/32 Profsouznaya, Moscow 117997, Russia
[d] Institut de Physique du Globe de Paris, 1 Rue Jussieu, 75238 Paris Cedex 05, France

Process for determining actions to implement in response to an earthquake prediction. Smaller bold rectangular boxes provide specific information related to the larger boxes.



Contemporary Science can do a better job in disclosing Natural Hazards, assessing Risks, and delivering such info in advance extreme catastrophes, which are

LOW PROBABILITY EVENTS THAT HAPPEN WITH CERTAINTY, i.e. 100%.

Geoscientists must initiate shifting the minds of community from pessimistic disbelieve to optimistic challenging issues of

neo-deterministic Hazard Predictability.

Thank you!

"When sorrows come, they come not single spies, but in battalions"
(William Shakespeare, 1564-1616)