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Predictability of Seismic Extremes

МИТП РАН / IIEPT

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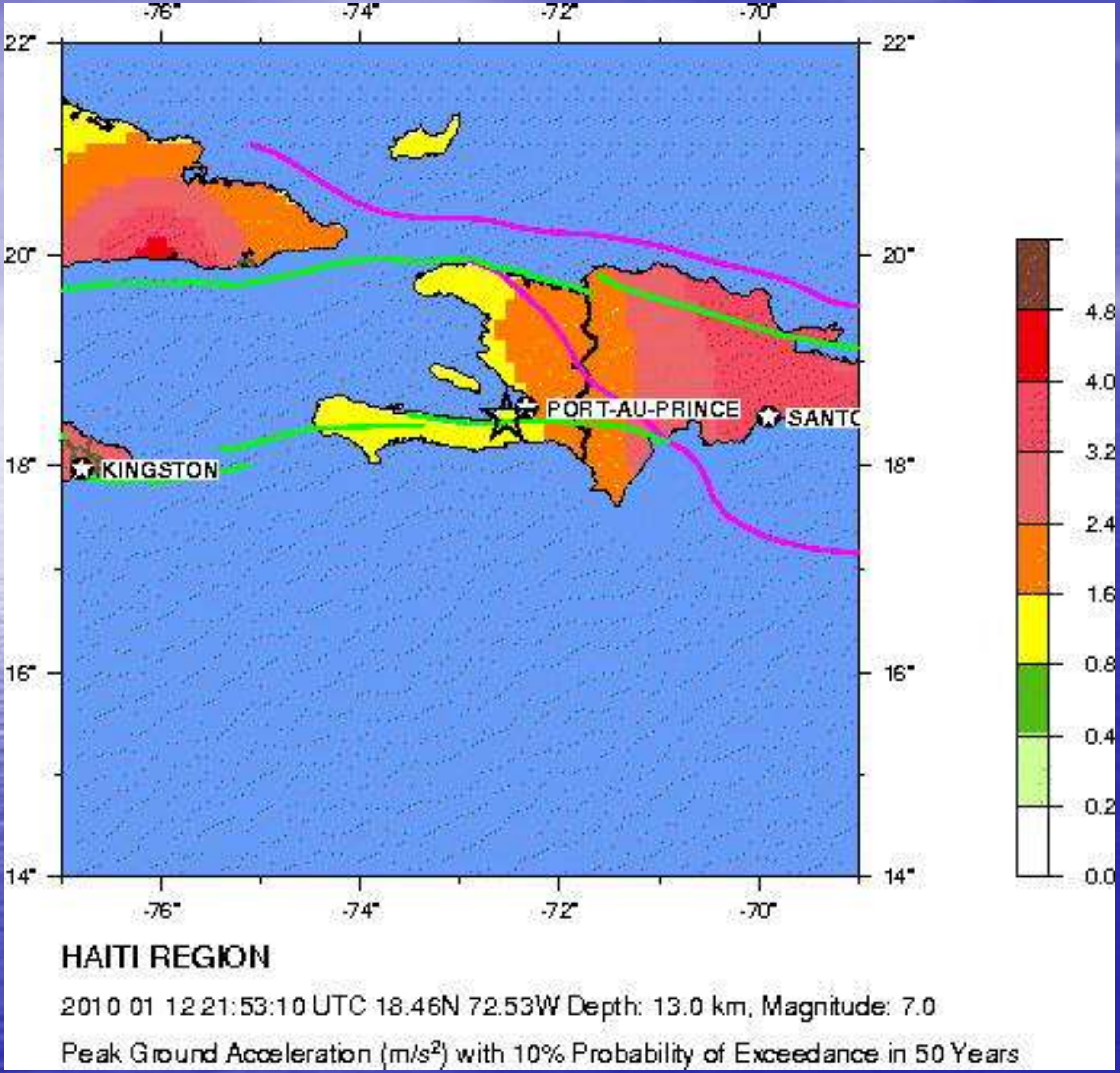
Our understanding of seismic process in terms of non-linear dynamics of a hierarchical system of blocks-and-faults and deterministic chaos progress to new approaches in assessing seismic hazard based on pattern recognition, multi-scale analysis of seismic activity, and reproducible intermediate-term earthquake prediction technique. The algorithms, which reliability is confirmed by durable statistical testing in the on-going regular real-time application, make use of multidisciplinary data available and account for fractal nature of earthquake distributions in space and time. The analysis of seismic sequences within space-time of long-, intermediate-, and short-term scales evidence consecutive stages of rather complex inverse cascading of seismic activity to the main shock and direct cascading of aftershocks. The first may reflect coalescence of instabilities at the approach of a catastrophe, while the second indicates certain state of readjustments in the system after it.

We present characteristics of spatially distributed seismic flux dynamics within long-, intermediate-, and short-term scales in advance and after some main shocks, including the 27 February 2010 Chile, 11 March 2011 Japan, and other recent mega- and great earthquakes. Although "Times of Increased Probability" were diagnosed by the same algorithm in advance 14 out of 19 magnitude M8.0+ earthquakes in the on-going real-time Global Test, 1992-2011, our results do not support the presence of "universality" in sequences of seismic inverse and direct cascades. In particular, the inter-event time distributions demonstrate a wide spectrum of the observed scaling that cannot be collapsed (by the two-parametric family of affine transforms) onto a single "model" curve describing either foreshock or aftershock behavior.

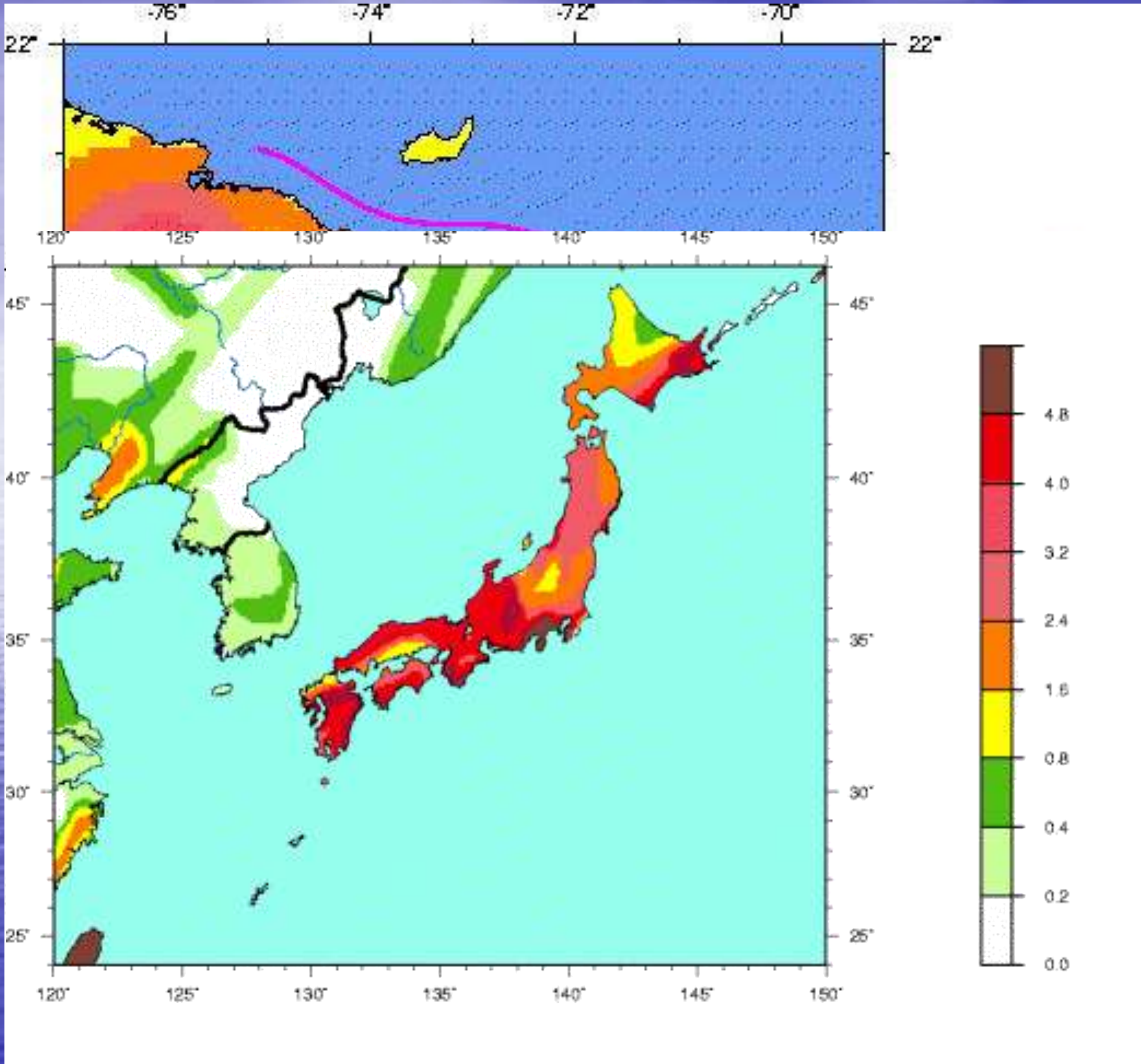
Why we face up failures of earthquake preparations?

- Losses from natural disasters continue to increase mainly due to the lack of knowledge and poor understanding by the majority of scientific community, as well as by decision makers and people, the three components of **Risk**,

  i.e., **Hazard, Exposure, and Vulnerability**.
- Contemporary Science, Geophysics and Seismology, in particular, is responsible for not coping with challenging changes of **Exposures** and their **Vulnerability** inflicted by growing population, its concentration, etc., which result in a steady increase of **Losses** due to Natural Hazards.
- Scientists owe to Society for lack of knowledge, education, and communication. Some cases of recent disastrous earthquakes are on the limit of unacceptable fault committed by technocrats and their advisers.

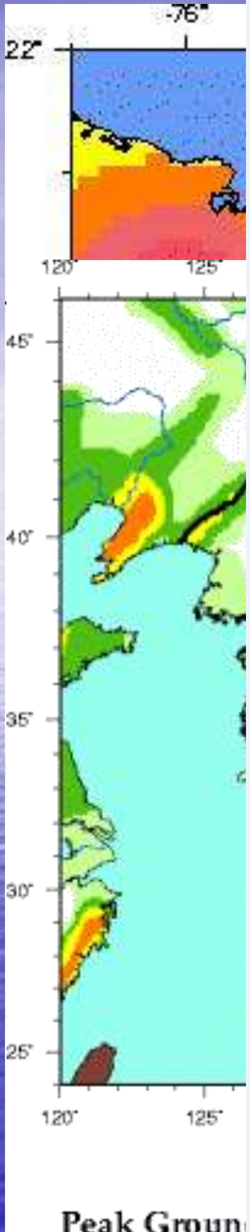


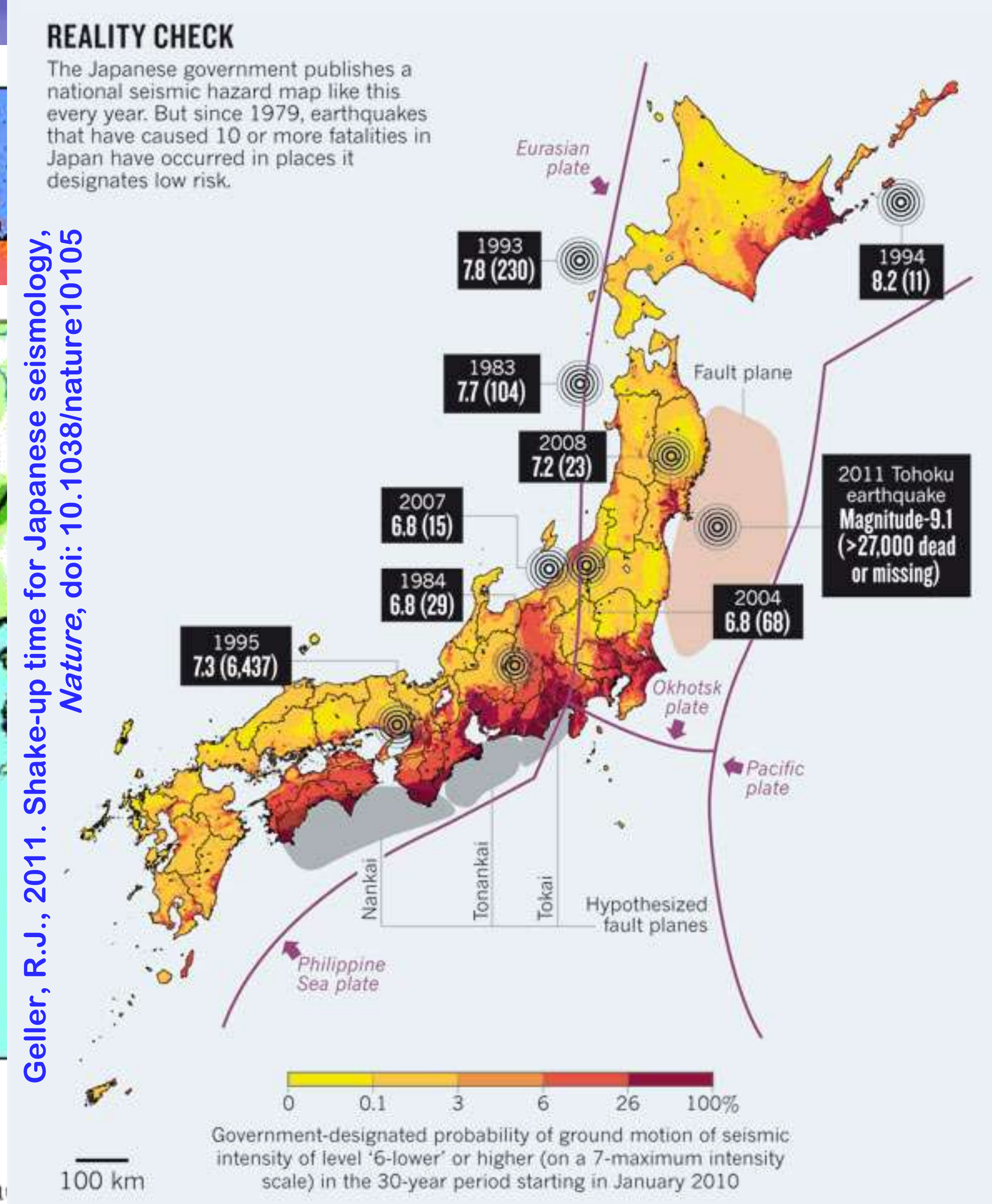
The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural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



Peak Ground Acceleration (m/s^2) with 10% Probability of Exceedance in 50 Years

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 .





Geller, R.J., 2011. Shake-up time for Japanese seismology, *Nature*, doi: 10.1038/nature10105

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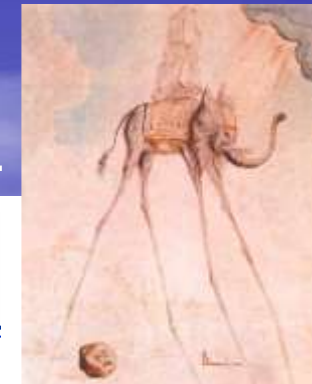
…**endorsed as a demonstration program** in the framework of the United Nations International Decade for Natural Disaster Reduction…

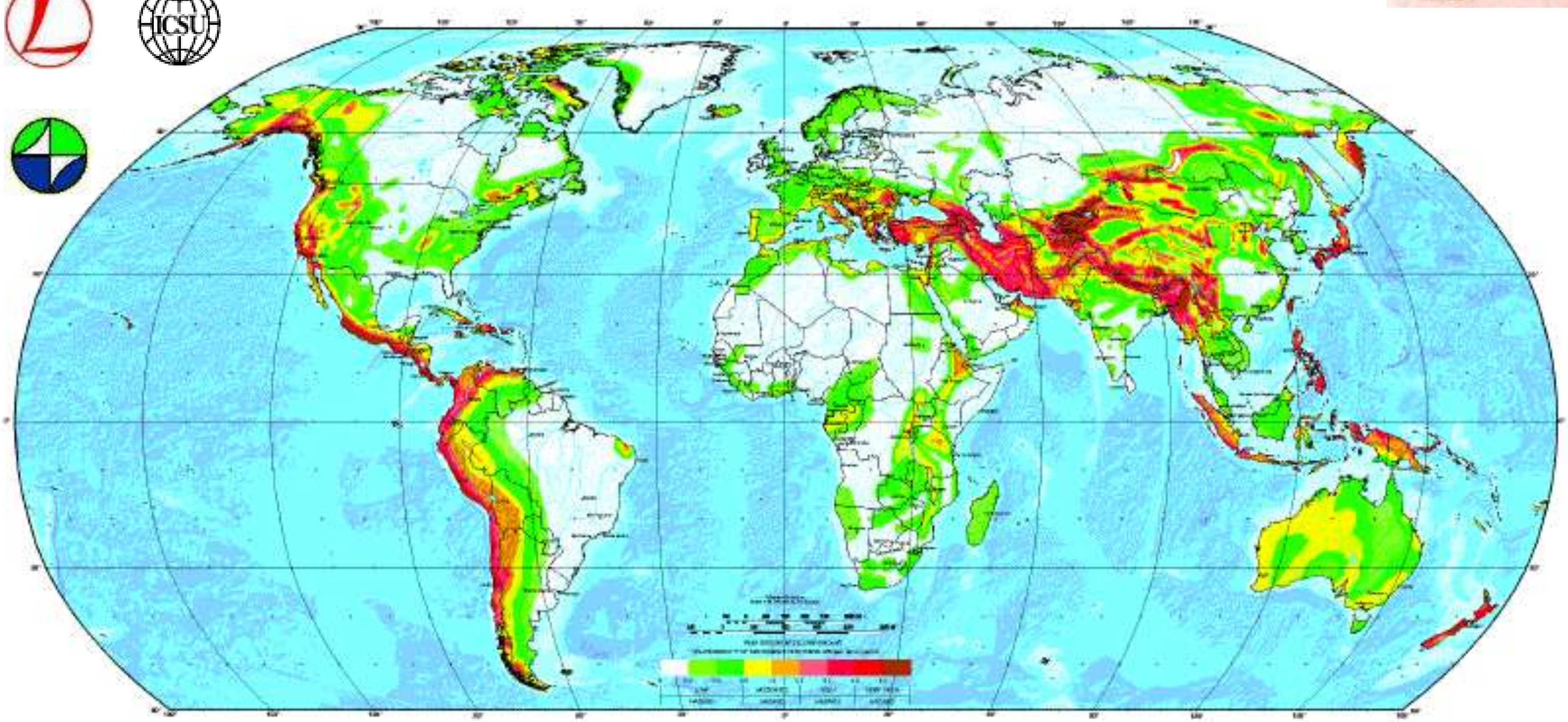


International Decade for Natural Disaster Reduction

IDNDR

1990 – 2000

GLOBAL SEISMIC HAZARD MAP

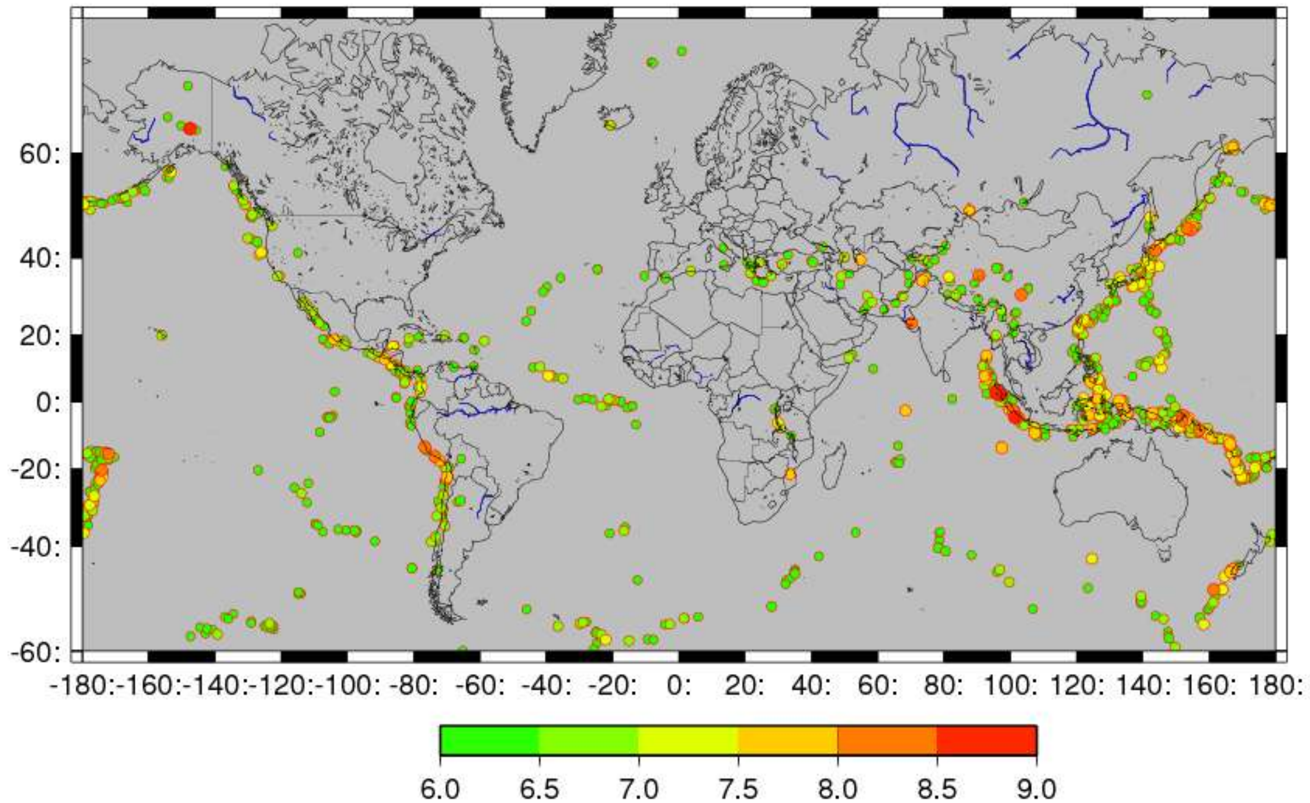


GeoForschungsZentrum Potsdam

USGS science for a changing world

SED ETH

Since the GSHAP terminated, seismic reality was testing the prediction given by Global Seismic Hazard Map.



USGS/NEIC Global Hypocenter's Data Base, 2000-2010

Kosobokov, V. G., Nekrasova, A. K, 2011 . Global Seismic Hazard Assessment Program (GSHAP) Maps Are Misleading. *Problems of Engineering Seismology*, **38** (1), 65-76 (in Russian).

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, while 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

"Top Twelve Deadliest Earthquakes, 2000-2011"

Region	Date	*M*	Fatalities	ΔI_0
Sumatra-Andaman "Indian Ocean Disaster"	26.12.2004	9.0	227898	4.0
Port-au-Prince (Haiti)	12.01.2010	7.3	222570	2.2
Wenchuan (Sichuan, China)	12.05.2008	8.1	87587	3.2
Kashmir (North India and Pakistan border region)	08.10.2005	7.7	~86000	2.3
Bam (Iran)	26.12.2003	6.6	~31000	0.2
Bhuj (Gujarat, India)	26.01.2001	8.0	20085	2.9
Off the Pacific coast of Tōhoku (Japan)	11.03.2011	9.0	15477 (7464 missing)	3.2
Yogyakarta (Java, Indonesia)	26.05.2006	6.3	5749	0.3
Southern Qinghai (China)	13.04.2010	7.0	2698	2.1
Boumerdes (Algeria)	21.05.2003	6.8	2266	2.1
Nias (Sumatra, Indonesia)	28.03.2005	8.6	1313	3.3
Padang (Southern Sumatra, Indonesia)	30.09.2009	7.5	1117	1.8

The contributors to GSHAP could have evaluate the poor performance of their product before its publication in 1999…

Table 1. Number of shallow earthquakes (in a decade) that violate GSHAP PGA prediction.

	Total	$\Delta I_0 = I_0(M) - I_0(mPGA)$											
		(2)			(3)			(4)			(5)		
		> 0	> 1	> 2	> 0	> 1	> 2	> 0	> 1	> 2	> 0	> 1	> 2
2000-2009 (test on control sample, after publication)													
M = 6 or more	1181	529	191	83	530	204	89	559	232	105	426	164	78
M = 7 or more	113	113	79	28	112	76	30	106	74	35	105	65	25
1990-1999 (test on learning sample)													
M = 6 or more	1021	471	182	66	463	185	69	487	203	91	385	137	61
M = 7 or more	129	124	74	15	120	65	16	117	63	22	115	46	11

Aptikaev et al, 2008 (2), *Shteinberg et al, 1993* (3), *Sauter and Shah, 1978* (4), and *Murphy and O'Brien, 1977* (5)

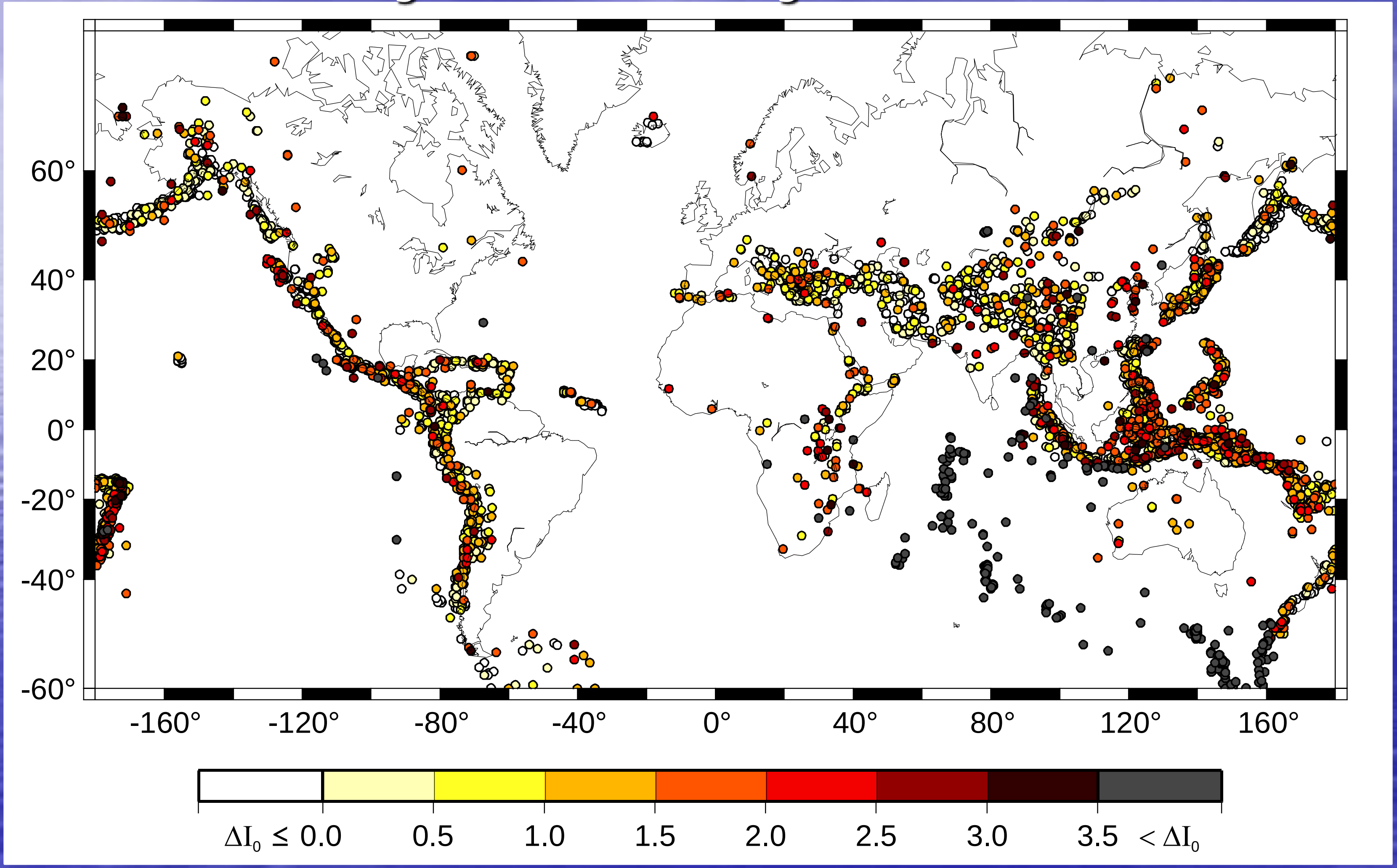
Rare cases of actual measurements of strong ground acceleration and field surveys of earthquake intensity at the sites of recent strong earthquakes and numerous data at some distance from the M9.0 11 March 2011 Tōhoku mega-thrust epicenter are in full agreement with our results (achieved by a crude computation), and essentially confirm the basic validity of our results.

Table 1

Comparison between the expected and observed PGA for some recent strong earthquakes. Where available, the computed DGA is reported as well. Values marked with the asterisk (*) denote PGA inferred from intensity. If non-linear effects (e.g. liquefaction) are considered the PGA values may be smaller

Earthquake	Expected PGA (g) with a probability of exceedance of 10% in 50 years (return period 475 years)	Observed PGA (g)	Computed DGA (g)
Kobe	0.40–0.48	0.7–0.8	
Gujarat	0.16–0.24	0.5–0.6	0.3–0.6
Boumerdes	0.08–0.16	0.3–0.4*	0.4–0.6
Bam	0.16–0.24	0.7–0.8	
Eastern Sichuan	0.16–0.24	0.6–>0.8 (Shakemap)	
Haiti	0.08–0.16	0.3–0.6*	

The color coded discrepancy, ΔI_0, between actual and GSHAP predicted effect at epicenters of strong shallow earthquakes in 1900-2009. "Surprises" dominate, while "big surprises" (i.e., $\Delta I_0 > 1$) are widespread throughout all seismic regions worldwide.



Conclusion:

Thus, a systematic and quantitative comparison of the GSHAP peak ground acceleration estimates (a 10% chance of exceedance in 50 years**) with those related to actual strong earthquakes, unfortunately, discloses gross inadequacy of this "probabilistic" product; which, in common sense, is evidently**

UNACCEPTABLE FOR ANY KIND OF RESPONSIBLE SEISMIC RISK EVALUATION AND KNOWLEDGEABLE DISASTER PREVENTION.

The self-evident shortcomings and failures of GSHAP appeals to all earthquake scientists and engineers for an urgent revision of the global seismic hazard maps from the first principles including the background methodologies involved, such that there becomes:

(1) a demonstrated and sufficient justification of hazard assessment protocols;

(2) a more complete learning of the actual range of earthquake hazards to local communities and populations, and

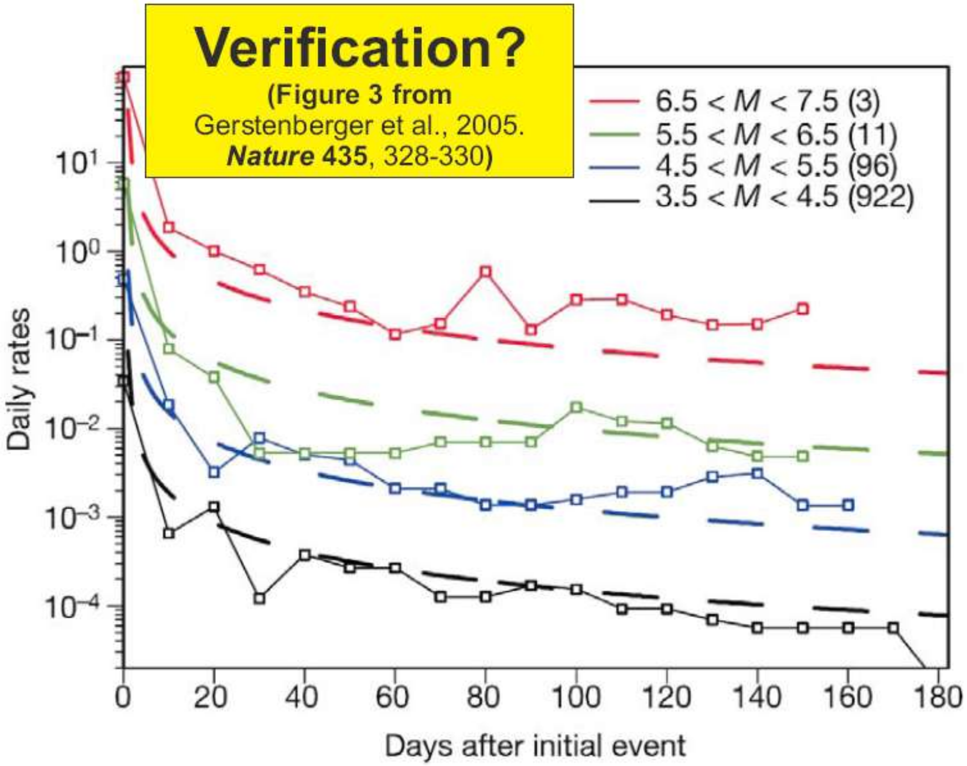
(3) a more ethically responsible control over how seismic hazard and seismic risk is implemented to protect the public safety.

On 19 May 2005, the United States Geological Survey began a public web site with forecasts of expected ground shaking for 'tomorrow' and *Nature* published the underlying work by *Gerstenberger et al*.

Gerstenberger, M. C., Wiemer, S., Jones, L. M. & Reasenberg, P. A. Real-time forecasts of tomorrow's earthquakes in California. *Nature* **435**, 328-331 (19 May 2005)

LETTERS NATURE|Vol 435|19 May 2005

Figure 3 | Calculated and observed rates of events *M* ≥ 4 in 24-hour intervals following mainshocks occurring between 1988 and 2002 in southern California. Dashed lines show the rates forecasted by the generic California clustering model (without cascades) for the mainshock magnitude (*M*) shown. For this test a simple circular aftershock zone implementation (solid lines) gives the observed rates of $M \geq 4.0$ aftershocks following all mainshocks with magnitude within 0.5 units of *M*. The aftershock zones are defined as the areas within one rupture length of the mainshock epicentre.



"As a first test, we verified that the generic clustering model describes the average clustering activity of California reasonably well. Using data from 1988−2002, after the period used to initially develop the model and thus independent data, we compute the average daily rate of events following an earthquake of a given size (Fig. 3)."

Statement: The data from 1988-2002 suggests rejecting the Generic Clustering Model for California.

Proof: Normalised by condition that the total integral of the p.d.f. (probability density function) increments equals 1, each of the four plots provides the minimum of positive p.d.f. increments, which are by definition either 1/N or its integer multiple (e.g., 2/N, 3/N, etc.). These are about 0.0012, 0.0008, 0.0025, and 0.0015, which values imply the sample sizes about 846, 1250, 401, and 665 or integer multiples of these values.

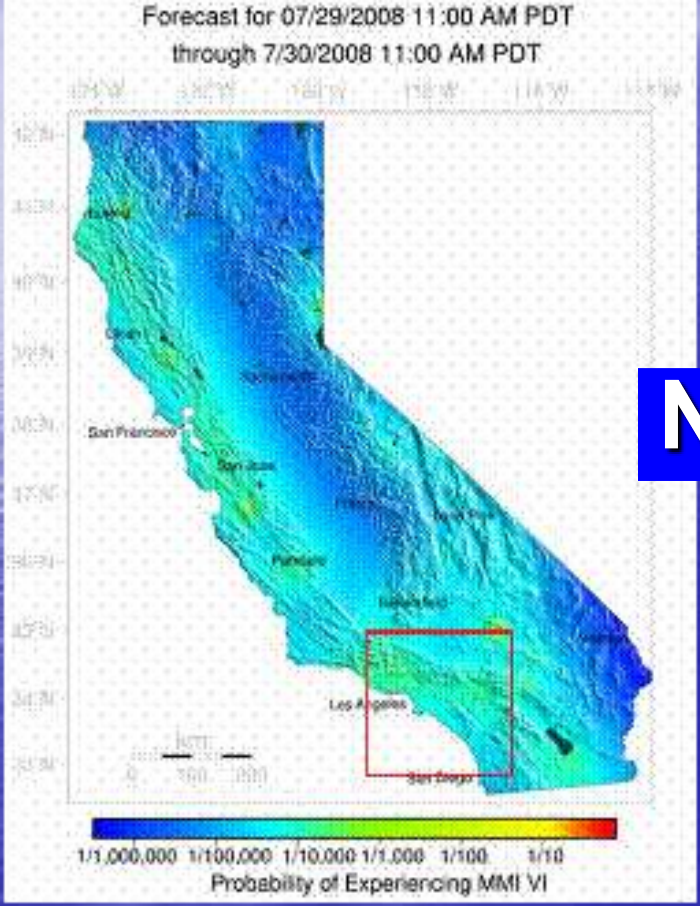
The probability of a smaller value of the Kolmogoroff-Smirnoff statistic D than that for the two samples used to plot the daily rates after $5.5 < M < 6.5$ (green plot in Figure 3) event and after $3.5 < M < 4.5$ (black plot) event (which D accounts to the value $D = \max | F_{green}(t) - F_{red}(t) | \cdot (N_1 N_2/(N_1+N_2))^{1/2} \geq 2.12$)

is larger than 97%.

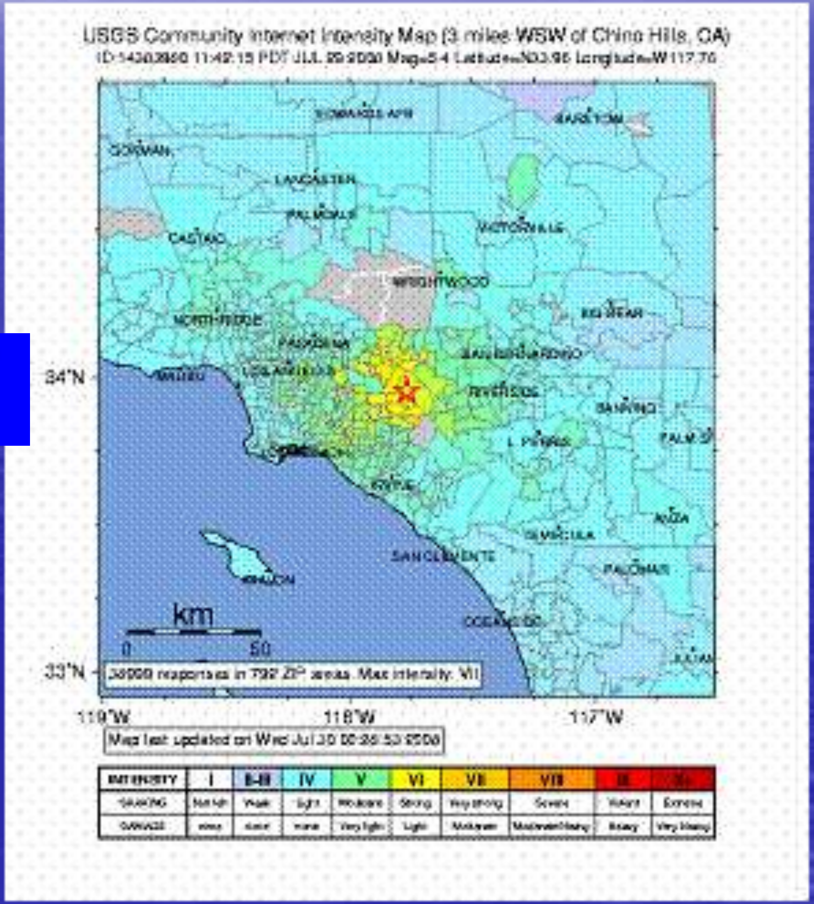
Therefore, the hypothesis that these two samples are drawn from the same distribution can be rejected at significance level of 0.03. ■

An example of the observed VI+ ground shaking in California

№ 7 (29 Jul 2008, M5.4 WSW of Chino Hills) **since the time of *Nature* published the work by *Gerstenberger et al 2005* -**



№ 7



The statistics of the observed ground shaking in California, 2005-present, demonstrate that

- earthquakes of Modified Mercalli intensity VI+ in California keep occurring in the "sky blue" areas of the lowest forecasted risk (p<1/10000),
- while the extent of the observed areas of intensity VI is by far less than the one expected from the calculations (currently a very crude low bound estimate of the ratio has surpassed a factor of 8.5…).

Kossobokov, V., Testing earthquake forecast/prediction methods: "Real-time forecasts of tomorrow's earthquakes in California". Geophysical Research Abstracts, Volume 10, 2008. Abstracts of the Contributions of the EGU General Assembly 2008, Vienna, Austria, 13-18 April 2008 (CD-ROM), EGU2008-A-07826

WHAT DO YOU WANT TO BE WHEN YOU GROW UP, DANAE?
A PRE-CONCEPTUAL SCIENTIST
UH...WHAT'S THAT?
IT'S THE NEW SCIENCE OF REACHING A CONCLUSION *BEFORE* DOING RESEARCH, THEN SIMPLY DISMISSING ANYTHING CONTRARY TO YOUR PRECONCEIVED NOTIONS
THAT'S GOT TO BE
DISMISSED...
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...SO AS A PRECONCEPTUAL SCIENTIST, YOU REACH A CONCLUSION TO A THEORY *FIRST*, THEN JUST IGNORE ALL EVIDENCE THAT PROVES YOU'RE WRONG?
YEP.
SO YOU BELIEVE YOU'RE ALWAYS RIGHT?
WELL, SINCE WE DON'T HEAR ANYTHING TO PROVE US WRONG, LOGIC DICTATES WE *MUST* BE RIGHT!
YEAH... BUT... JUST BECAUSE YOU WON'T LISTEN DOESN'T MEAN...
♫ LA-LA-LA-LA-LA-LA-LA ♫
I GIVE UP...
SEE HOW EASY IT IS?
WILEYINK@COMCAST.NET
6-8
UCOMICS.COM/NONSEQUITUR

"Men han har jo ikke noget paa," sagde et lille Barn. "Herre Gud, hør den Uskyldiges Røst," sagde Faderen; og den Ene hvidskede til den Anden, hvad Barnet sagde.

"Men han har jo ikke noget paa," raabte tilsidst hele Folket. Det krøb i Keiseren, thi han syntes, de havde Ret, men han tænkte som saa: "nu maa jeg holde Processionen ud". Og Kammerherrerne gik og bar paa Slæbet, som der slet ikke var.

Hans Christian Andersen, 1837. *Keiserens nye Klæder*

И.М. Гельфанд

ДВА АРХЕТИПА В ПСИХОЛОГИИ ЧЕЛОВЕЧЕСТВА

1989 Лекция при вручении премии INAMORI FOUNDATION

(Киото, Япония)

Izrail M. Gelfand, Two archetypes in the psychology of Man. Nonlinear Sci. Today 1 (1991), no. 4, 11

Izrail Moiseevich Gelfand (1913-2009)

"It is frightening that in our technocratic times baseline principles are not subjected to questioning, so that when they built the basis of **trivial or, conversely, delicately-designed model**, it **considered as a full replacement of natural phenomena**. This made the better model, it is worse for its applications – you know that pressure of snatched "baseline principles" brings the model even further beyond its applicability."

As we see, forecast/prediction of **extreme seismic events is not an easy task**.

- By definition, an extreme event is rare one in a series of kindred phenomena. Generally, it implies investigating a small sample of case-histories with a help of delicate statistical methods and data of different quality, collected in various conditions.
- Many extreme events are clustered (far from independent, e.g., Poisson process) and follow fractal or some other "strange" distribution (far from uniform). Evidently, such an "unusual" situation complicates search and definition of precursory behaviors to be used for forecast/prediction purposes.

- Making forecast/prediction claims quantitatively probabilistic in the frames of the most popular objectivists’ viewpoint on probability requires a long series of "yes/no" forecast/prediction outcomes, which cannot be obtained without an extended rigorous test of the candidate method.
- The set of errors (“success/failure” scores and space-time measure of alarms) and other information obtained in such a test supplies us with data necessary to judge the candidate’s potential as a forecast/prediction tool and, eventually, to find its improvements.
- This is to be done first in comparison against random guessing, which results confidence (measured in terms of statistical significance).

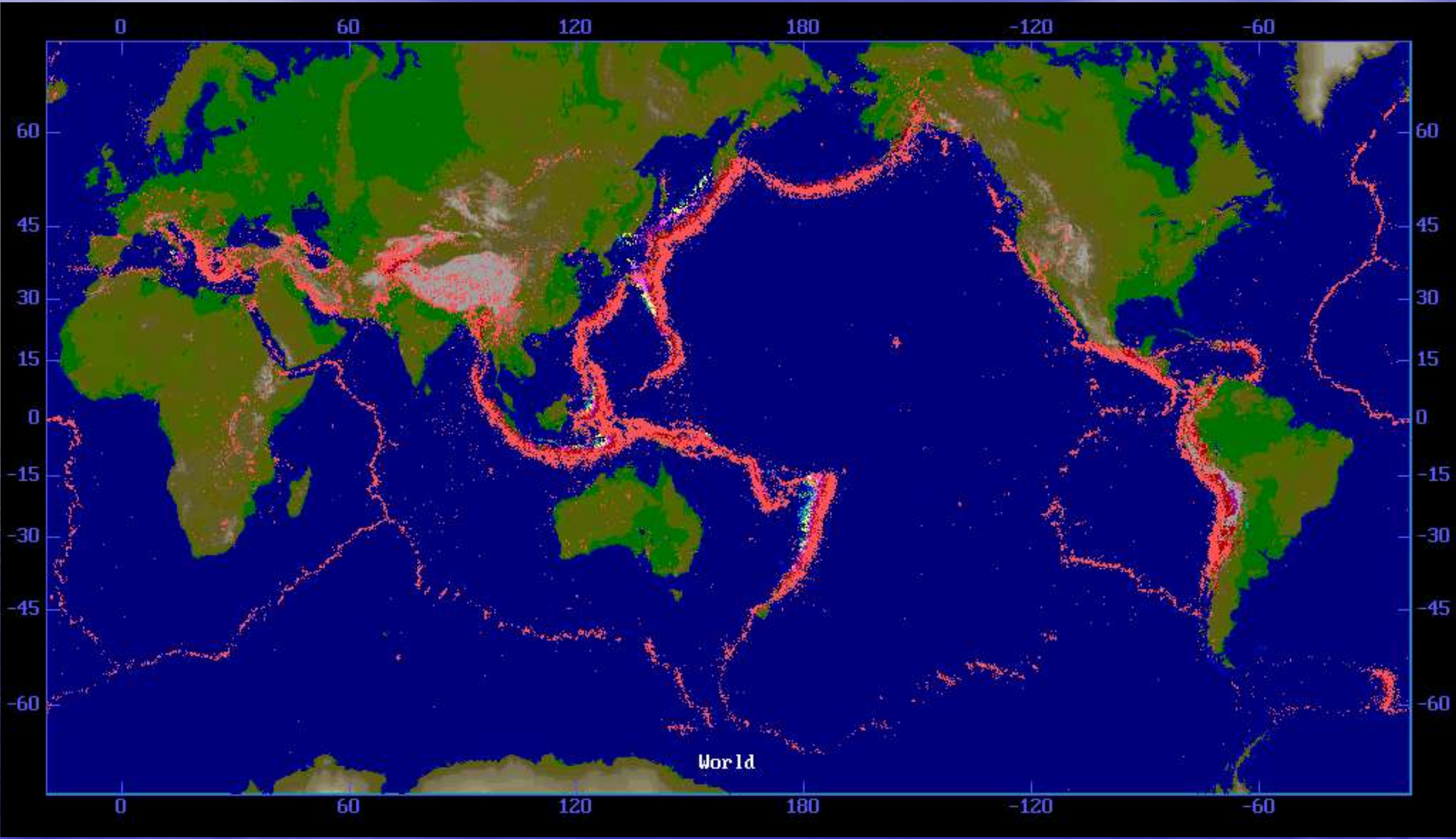
- Note that an application of the forecast/prediction tools could be very different in cases of different costs and benefits, and, therefore, requires determination of optimal strategies.
- In their turn case specific costs and benefits may suggest a modification of the forecast/prediction tools for a more adequate "optimal" application.

The extreme catastrophic nature of earthquakes is known for centuries due to resulted devastation in many of them.

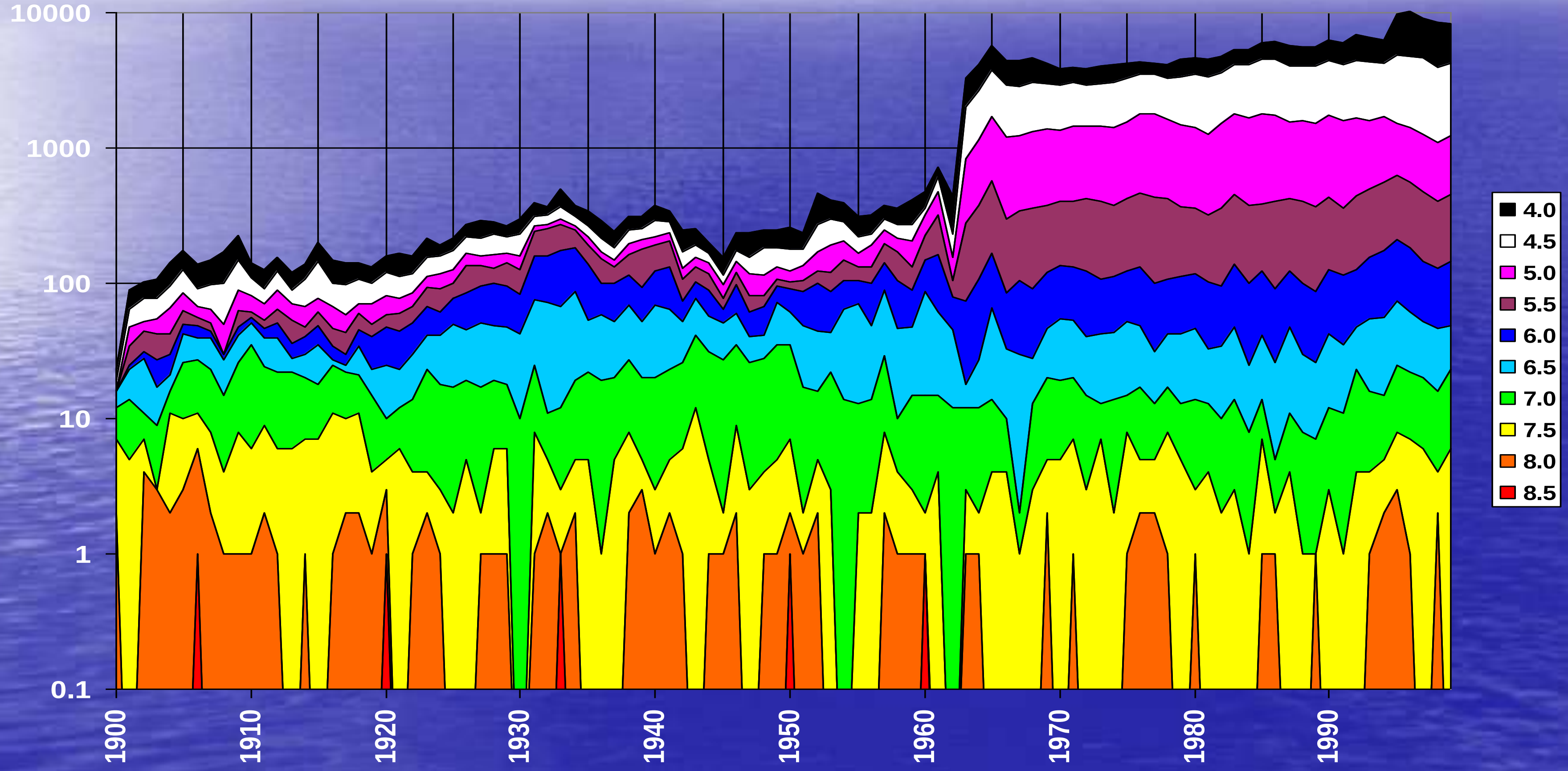
The abruptness along with apparent irregularity and infrequency of earthquake occurrences facilitate formation of a common perception that **earthquakes are random unpredictable phenomena.**

Is it so?

Distribution of earthquakes in Space



Distribution of earthquakes in Time:
Global Number of Earthquakes vs. Time



Seismic activity is self similar:

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., Болховитинов Л.Г., Писаренко В.Ф., 1982. О свойстве дискретности горных пород. *Изв. АН СССР. Физика Земли*, № 12, 3-18;
Садовский, М.А., Т.В. Голубева, В.Ф. Писаренко, и М.Г. Шнирман, 1984. Характерные размеры горной породы и иерархические свойства сейсмичности. *Известия АН СССР. Физика Земли*, 20: 87–96 .

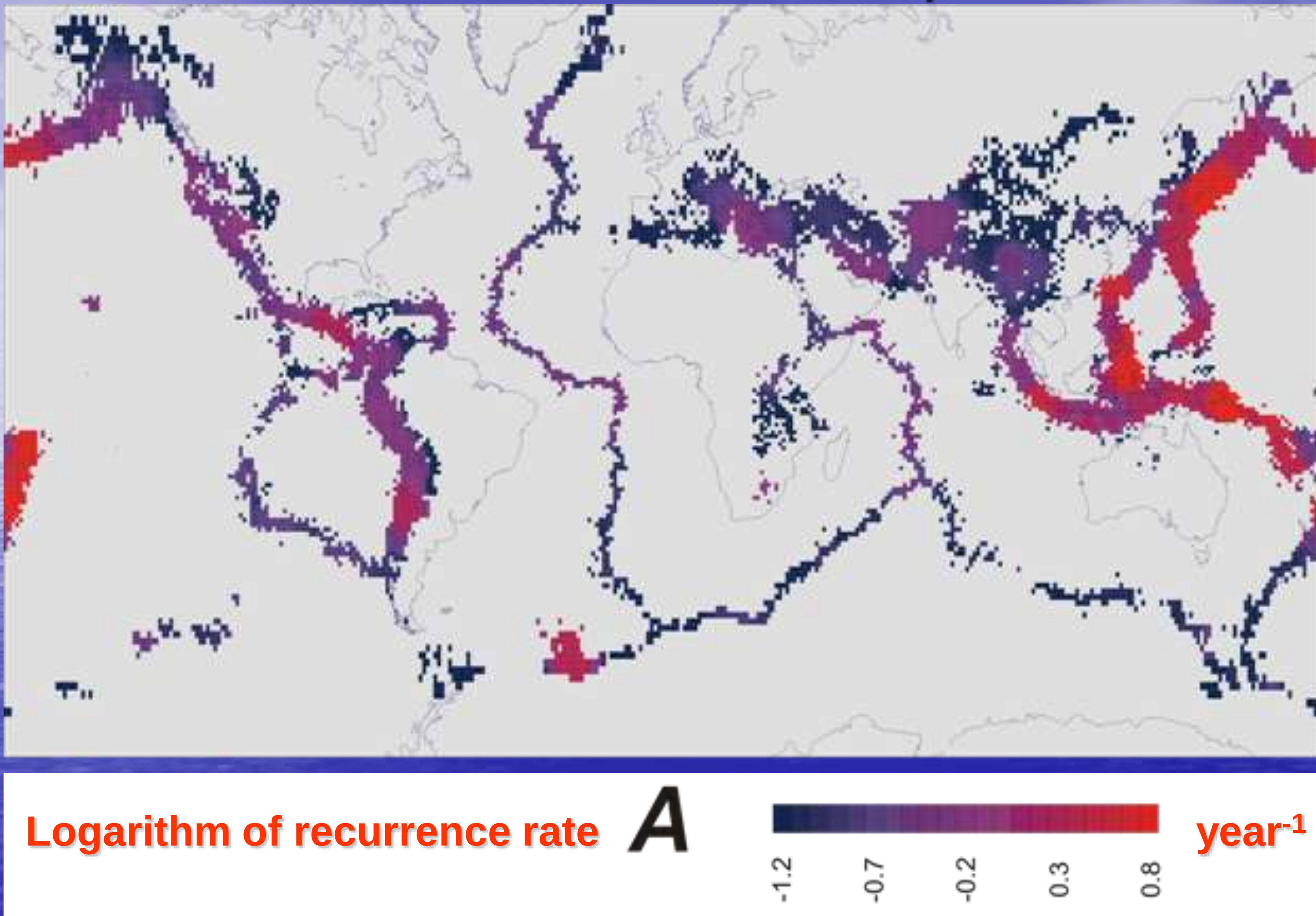
the understanding of the fractal nature of earthquakes and seismic processes keeps growing.

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

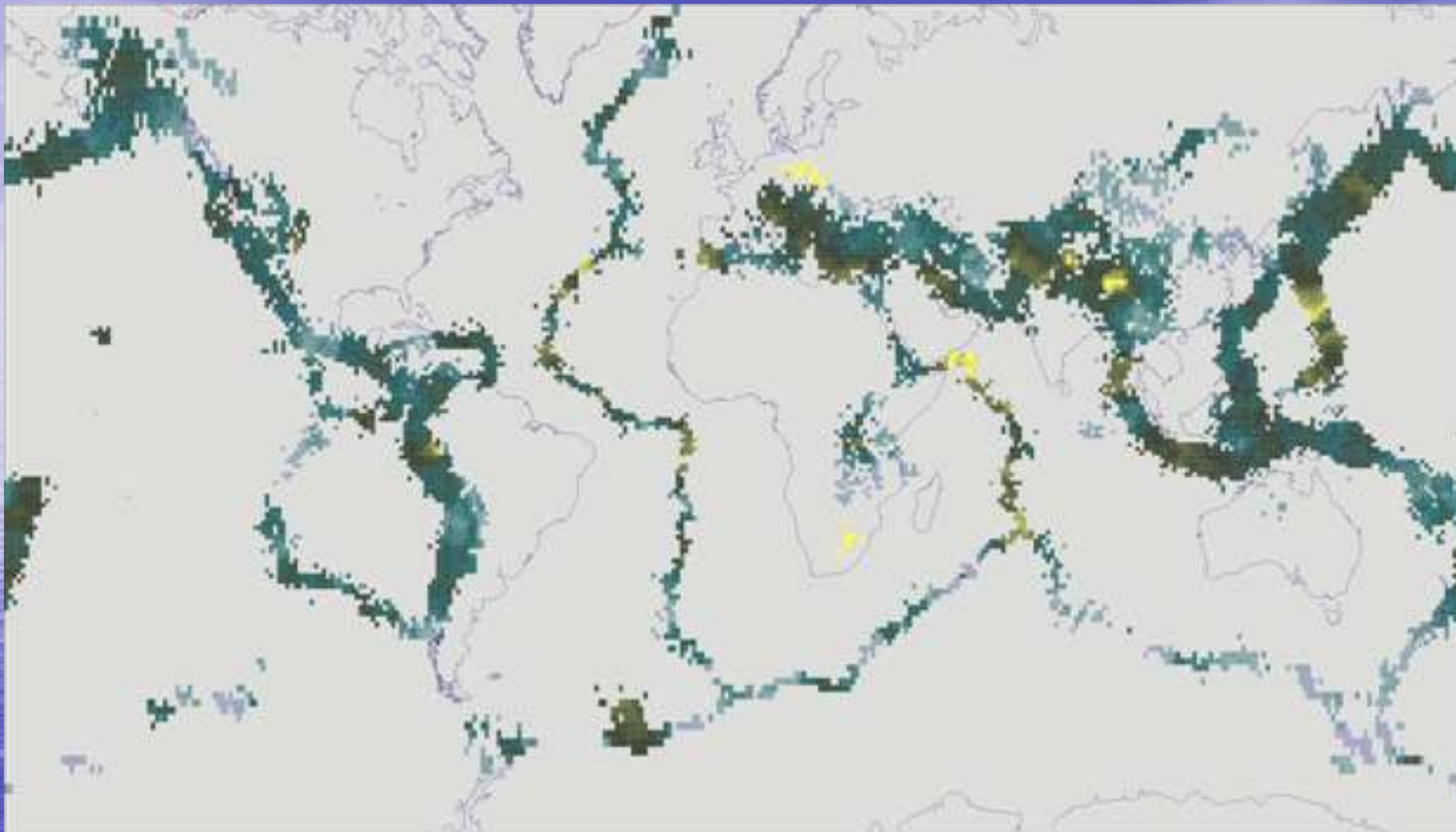
$$\log_{10}N = A + B\cdot(5 - M) + C\cdot\log_{10}L$$

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

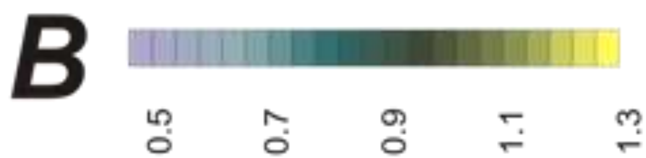
The Global Seismic Hazard map: Coefficient A



The Global Seismic Hazard map: Coefficient B

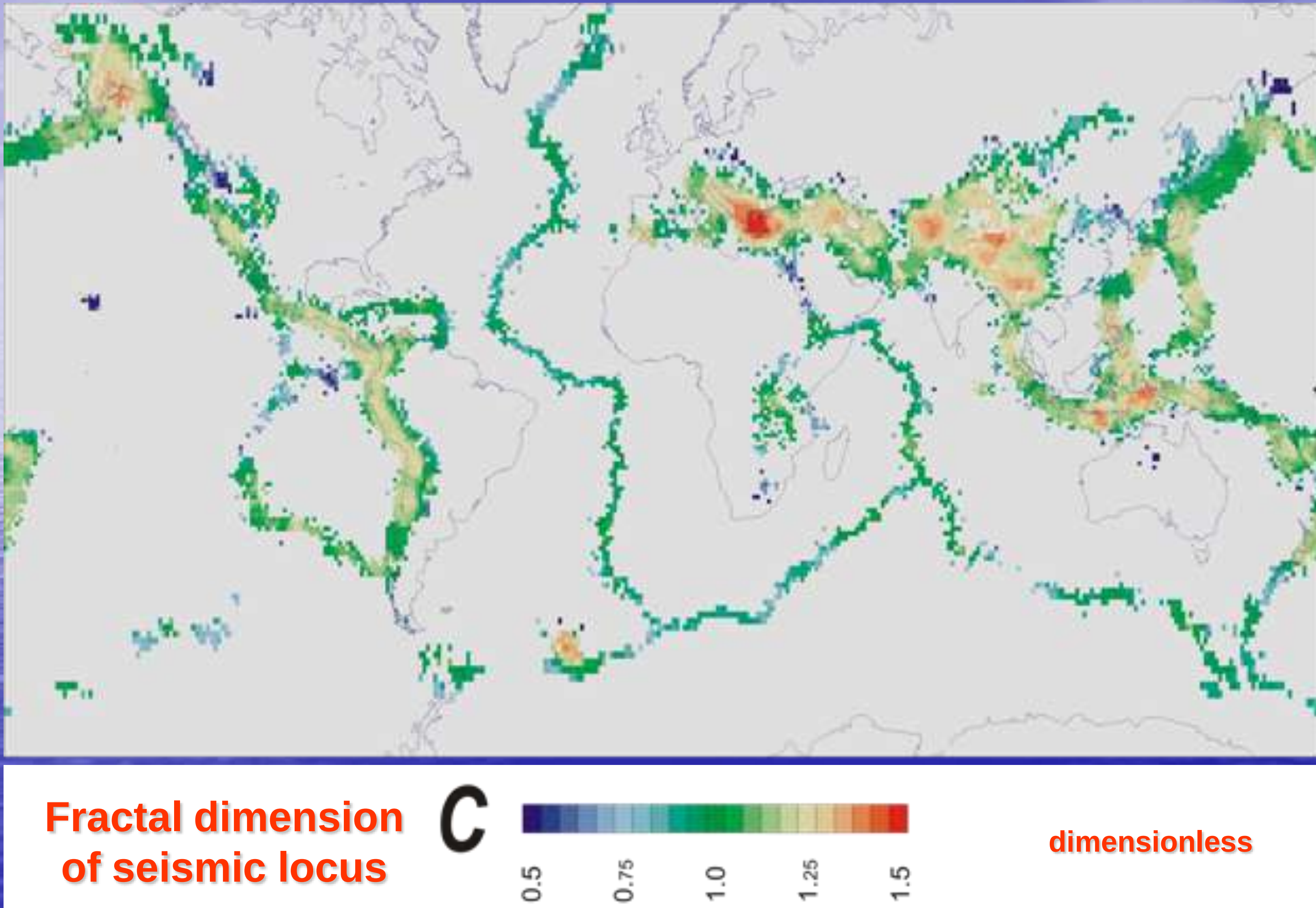


Magnitude balance relation



(magnitude unit)$^{-1}$

The Global Seismic Hazard map: Coefficient C



Direct implications for assessing seismic hazard at a given location (e.g., in a mega city)

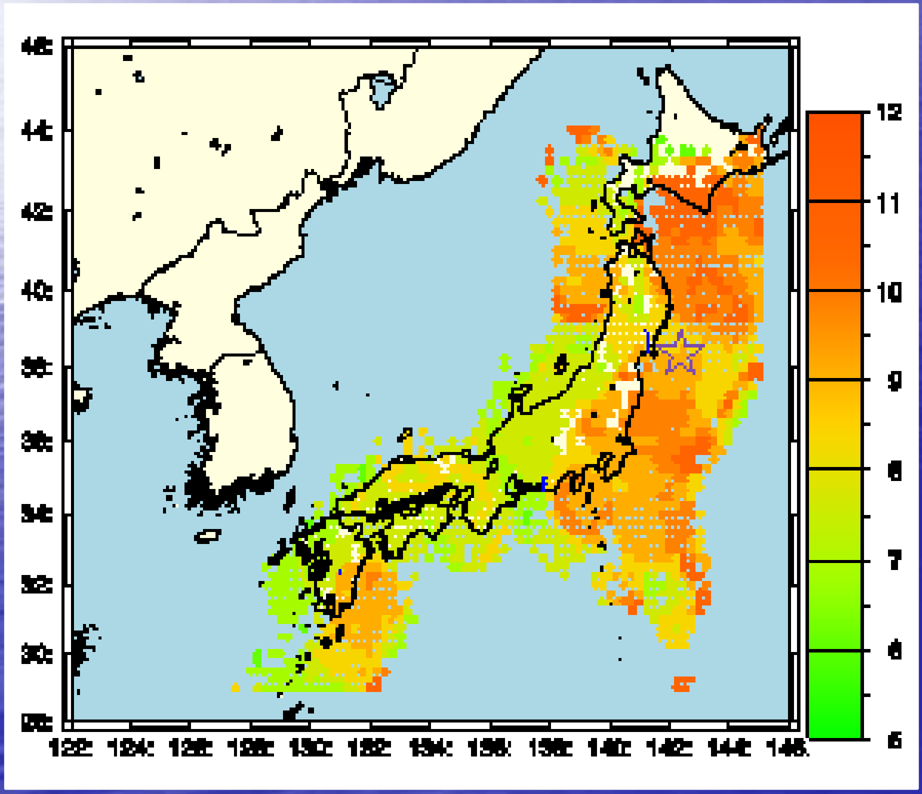
The estimates for Los Angeles (SCSN data, 1984-2001) -
A = -1.28;   B = 0.95; C =1.21 (σ_{total} = 0.035)
- imply a traditional assessment of recurrence of a large earthquake in Los Angeles,
i.e., an area with L about 40 km,
from data on the entire southern California, i.e., an area with L about 400 km,
being **underestimated by a factor of** $10^2 / 10^{1.21} = 10^{0.79}$ **> 6 !**

Similarly, the underestimation is about a factor of
6.4 for San Francisco (A = -0.38, B = 0.93, C = 1.20, σ_{total}=0.07),
4.6 for Tokyo (A = 0.14, B = 0.94, C = 1.34, σ_{total}=0.05),
8 for Petropavlovsk-Kamchatsky (A = -0.01, B = 0.83, C = 1.22, σ_{total}=0.05),
10 for Irkutsk (A = -1.12, B = 0.80, C = 1.05, σ_{total}=0.03),
etc.

Scaling for uniform application of earthquake prediction methods.

Unlike GSHAP Seismic Hazard Maps, those based on USLE do not fail predicting the 2011 Tōhoku mega-thrust off shore Eastern Honshu Island.

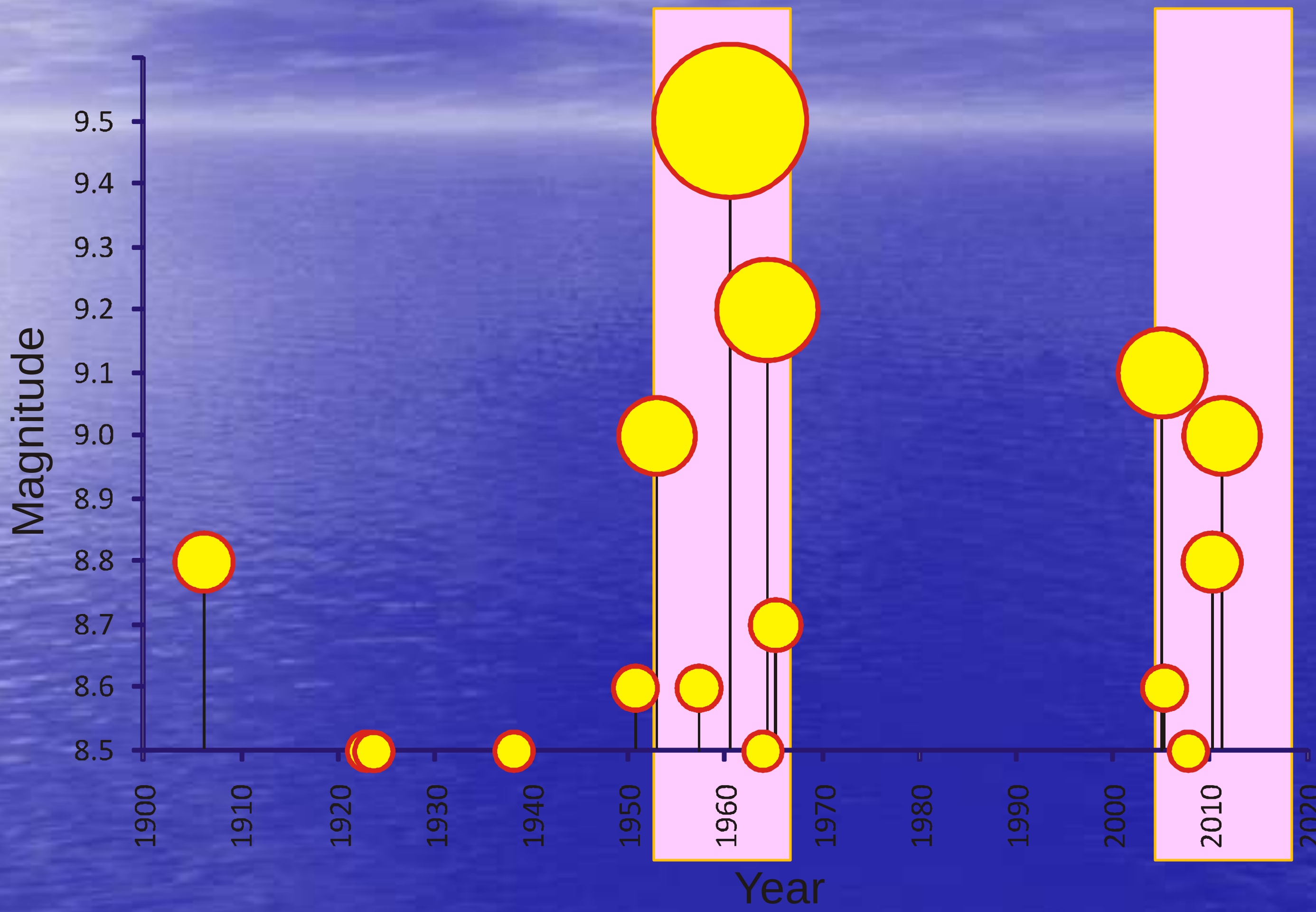
Kosobokov, V. G., Nekrasova, A. K., 2005. Temporal variations in the parameters of the Unified Scaling Law for Earthquakes in the eastern part of Honshu Island (Japan). *Doklady Earth Sciences*, **405**, 1352-1356.



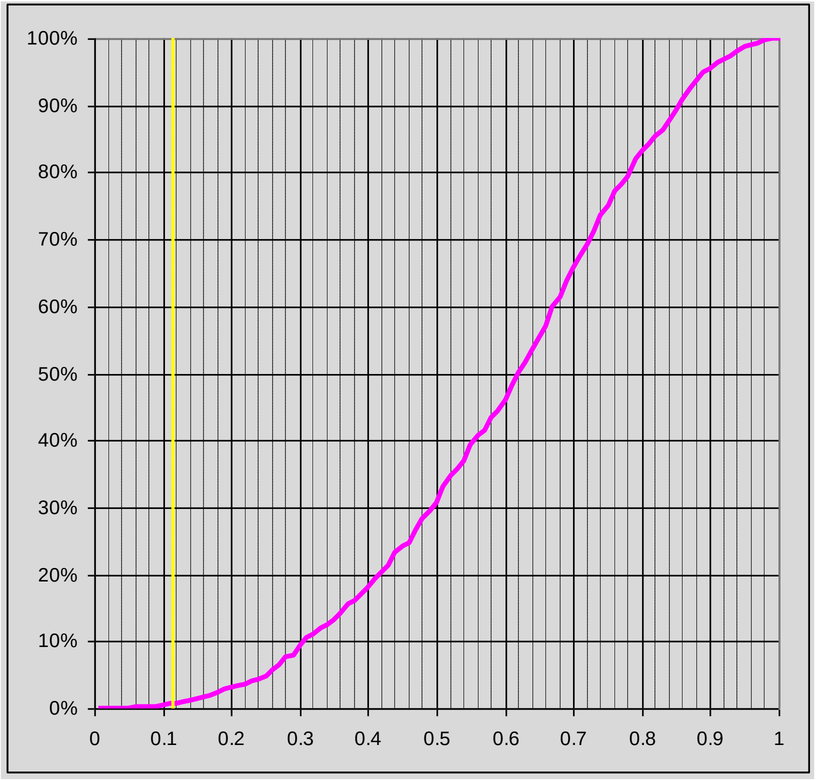
JMA earthquake catalog, 1980-2002

maximum I_0, 10% chance in 50 years.

Top magnitude earthquakes cluster in time



Location	Date UTC	Magnitude	Latitude	Longitude
5.Kamchatka	4-Nov-1952	9.0	52.76 N	160.06 E
4.Andreanof Islands, Alaska	9-Mar-1957	9.1	51.56 N	175.39 W
1.Chile	22-May-1960	9.5	38.24 S	73.05 W
3.Prince William Sound, Alaska	28-Mar-1964	9.2	61.02 N	147.65 W
2.Off the West Coast of Northern Sumatra	26-Dec-2004	9.3	3.30 N	95.78 E

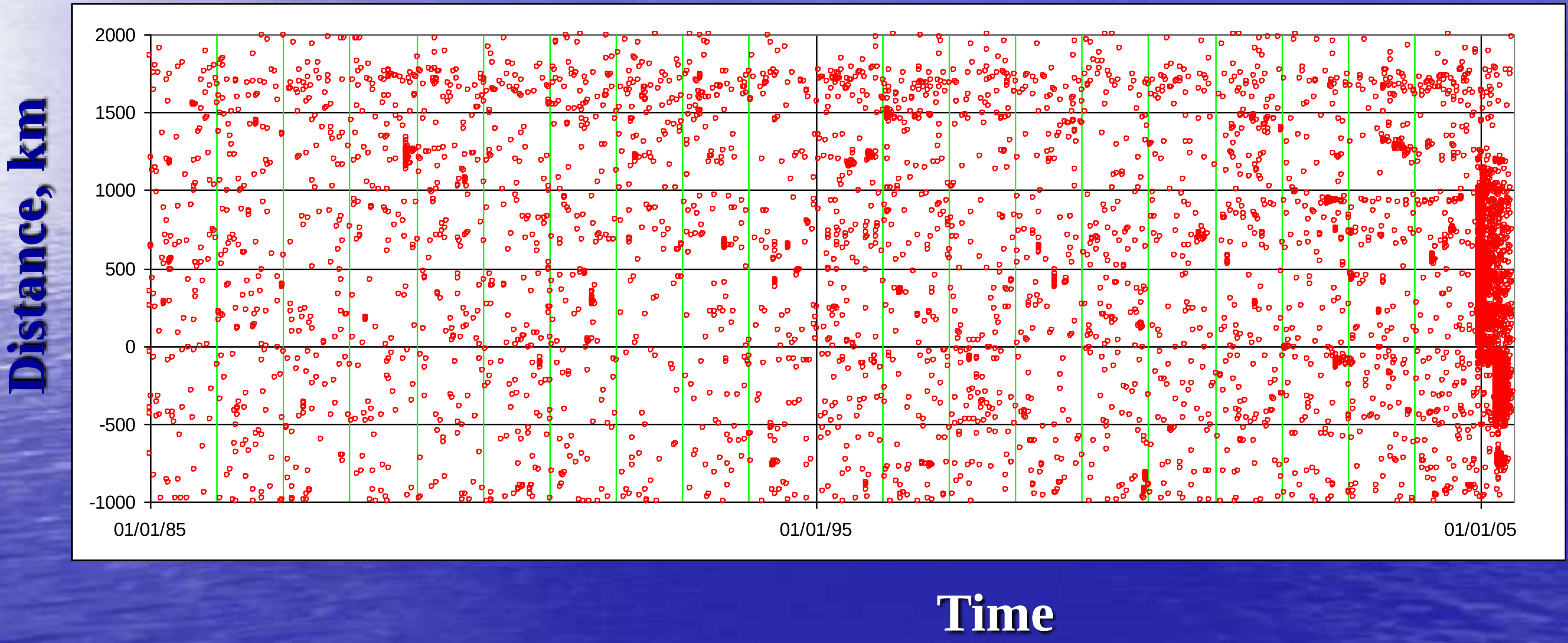


All four mega-earthquakes of the 20th century happened within a narrow interval of time. Such a cluster is unlikely with a 99% confidence for uniformly distributed independent events.

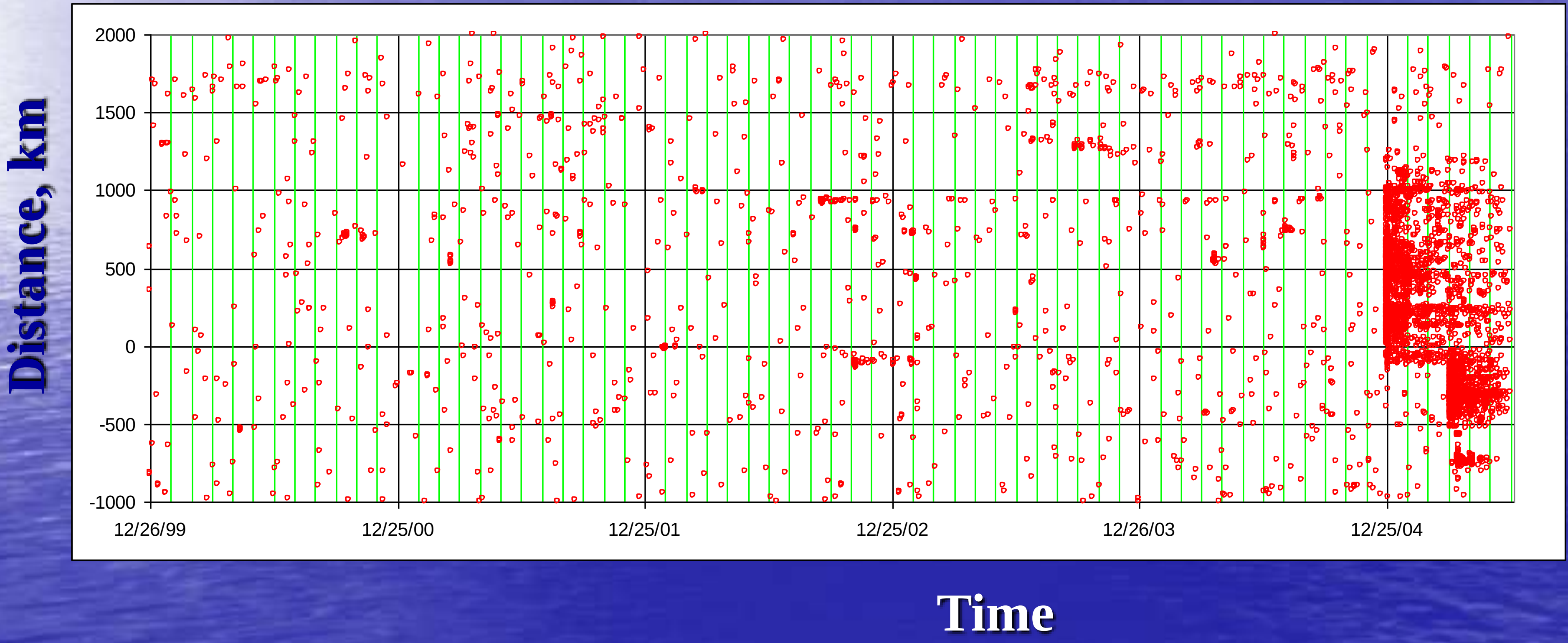
Thus, earthquakes, including the mega-ones, **cluster.**

Distribution of earthquakes in Space and Time:

Sumatra-Andaman region

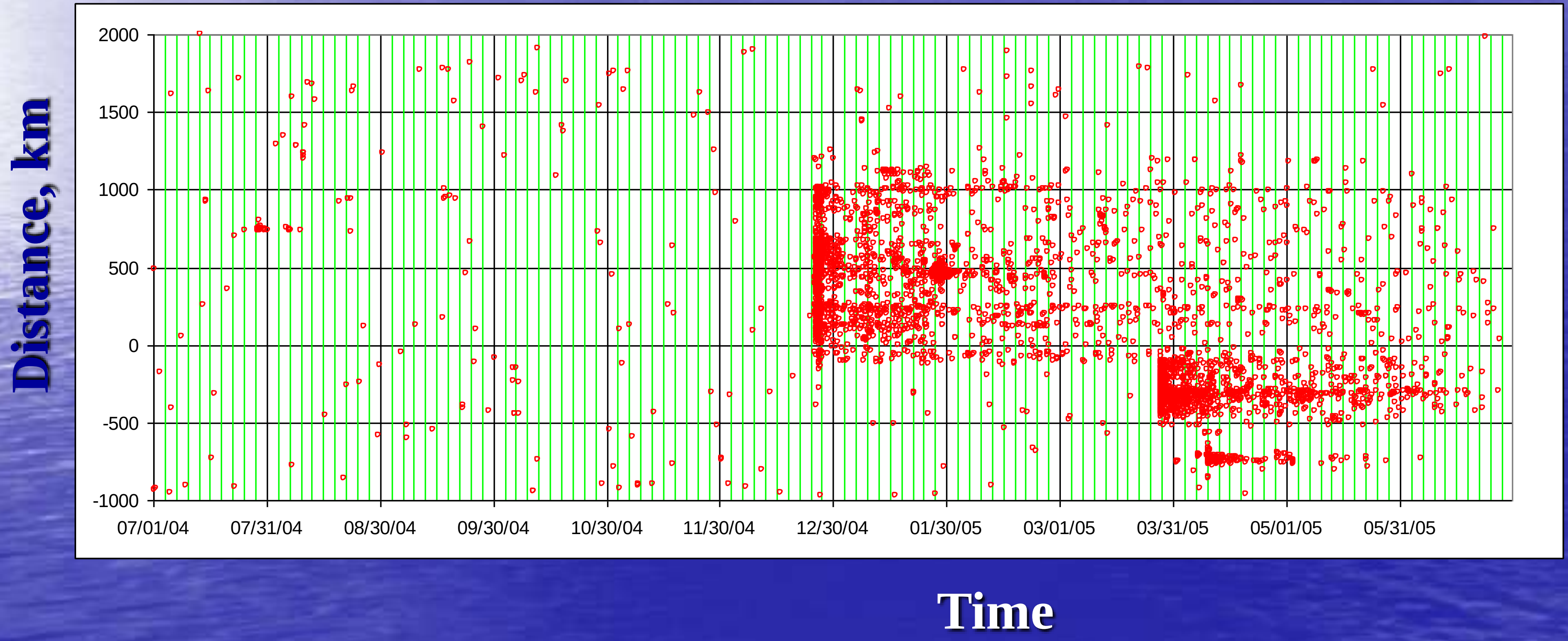


Distribution of earthquakes in Space and Time:
Sumatra-Andaman region



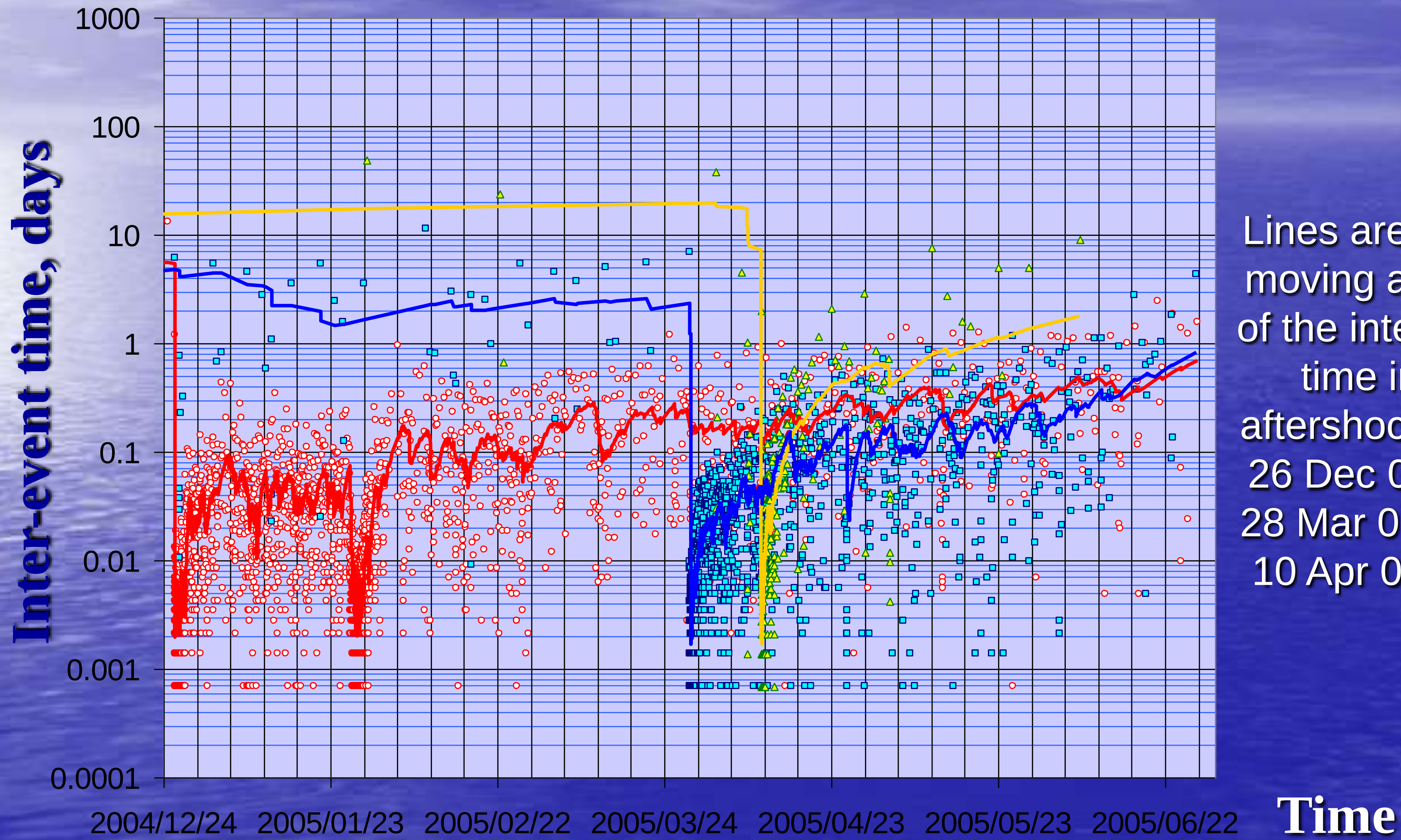
Distribution of earthquakes in Space and Time:

Sumatra-Andaman region



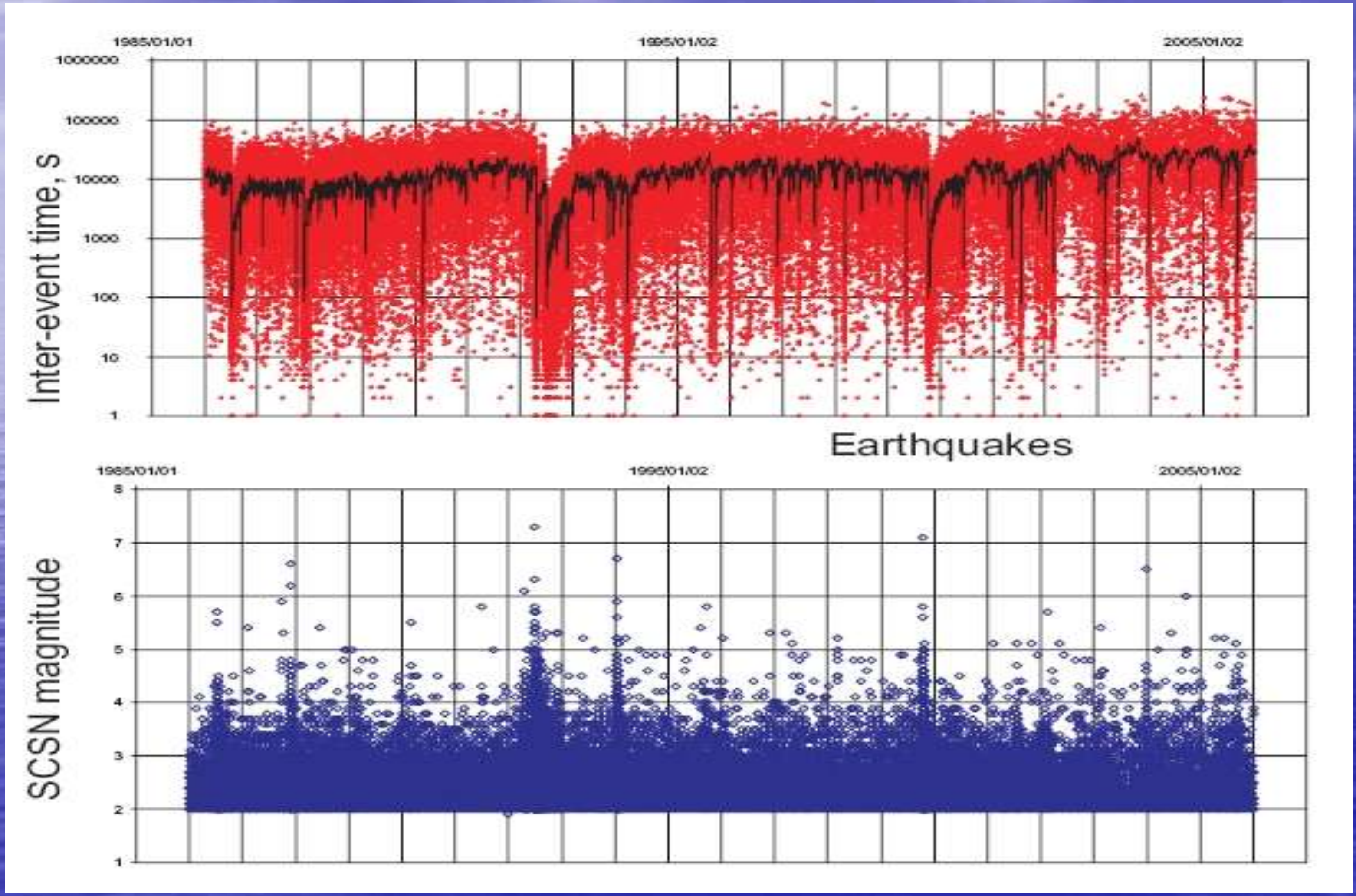
Distribution of earthquakes in Space and Time:

Clustering and cascades



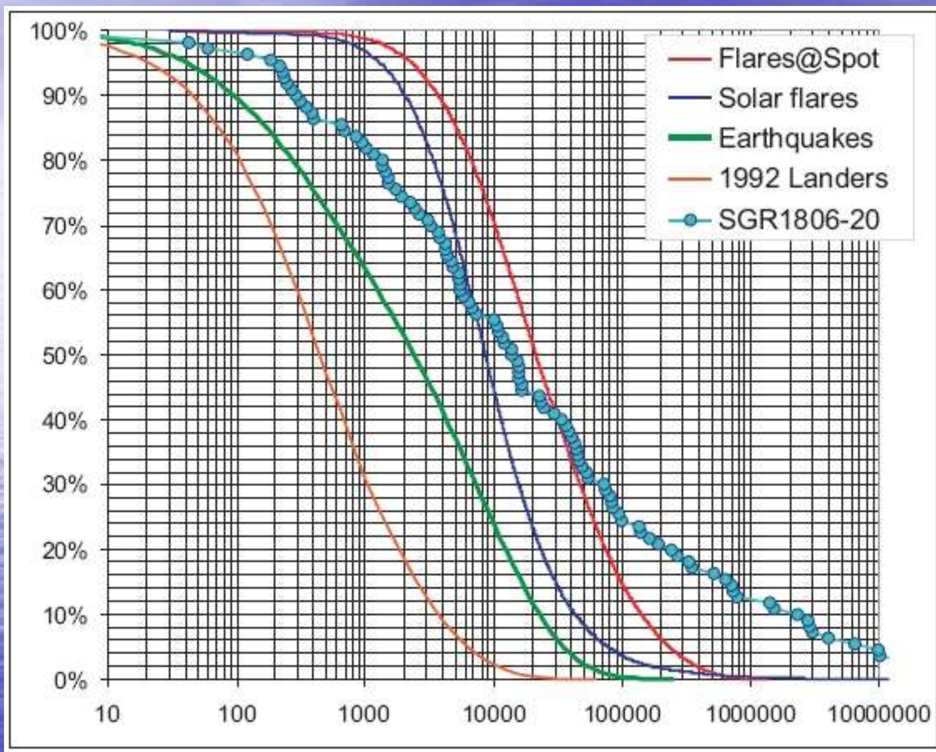
Lines are 20 per moving average of the inter-event time in an aftershock zone: 26 Dec 04 (red) 28 Mar 05 (blue) 10 Apr 05 (yellow)

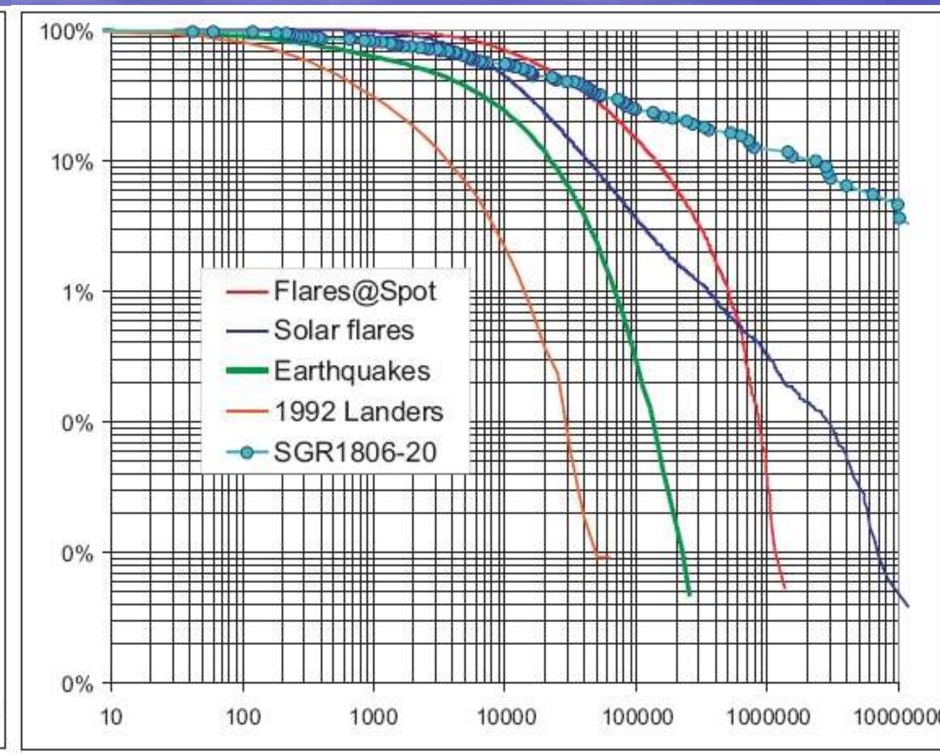
Inter-event times and magnitude vs. time



Inter-event time distributions for earthquakes, solar flares, and starquakes show significant differences

Kossobokov, V. G., Lepreti, F., Carbone, V.. Complexity in sequences of solar flares and earthquakes. *Pure Appl. Geophys.* **165** (2008) 761–775, DOI 10.1007/s00024-008-0330-z





- We calculated the minimum values of K-S statistic for all the couples of distributions over all rescaling fits of the type $P'(\Delta t)=P(C\,\Delta t^{\alpha})$, with C and α fitting constants

Inter-event time distributions compared with the Kolmogoroff-Smirnoff two-sample criterion

	Flares	Flares at spot	SCSN	Landers	SGR1806-20
Flares	32076	3.435	8.648	2.071	0.636
Flares at spot	100 %	18878	5.898	1.669	0.434
SCSN	100 %	100 %	87688	3.726	1.435
Landers	99.96%	99.26%	100 %	10706	0.47
SGR1806-20	19.13%	0.92%	96.77%	2.24%	110

- The results indicate that the distributions cannot be rescaled onto the same curve (confidence level > 99%)
- Only the association of the starquake distribution (by far the smallest sample, 111 events) with all flares, flares at an activity spot, and Landers event cannot be rejected

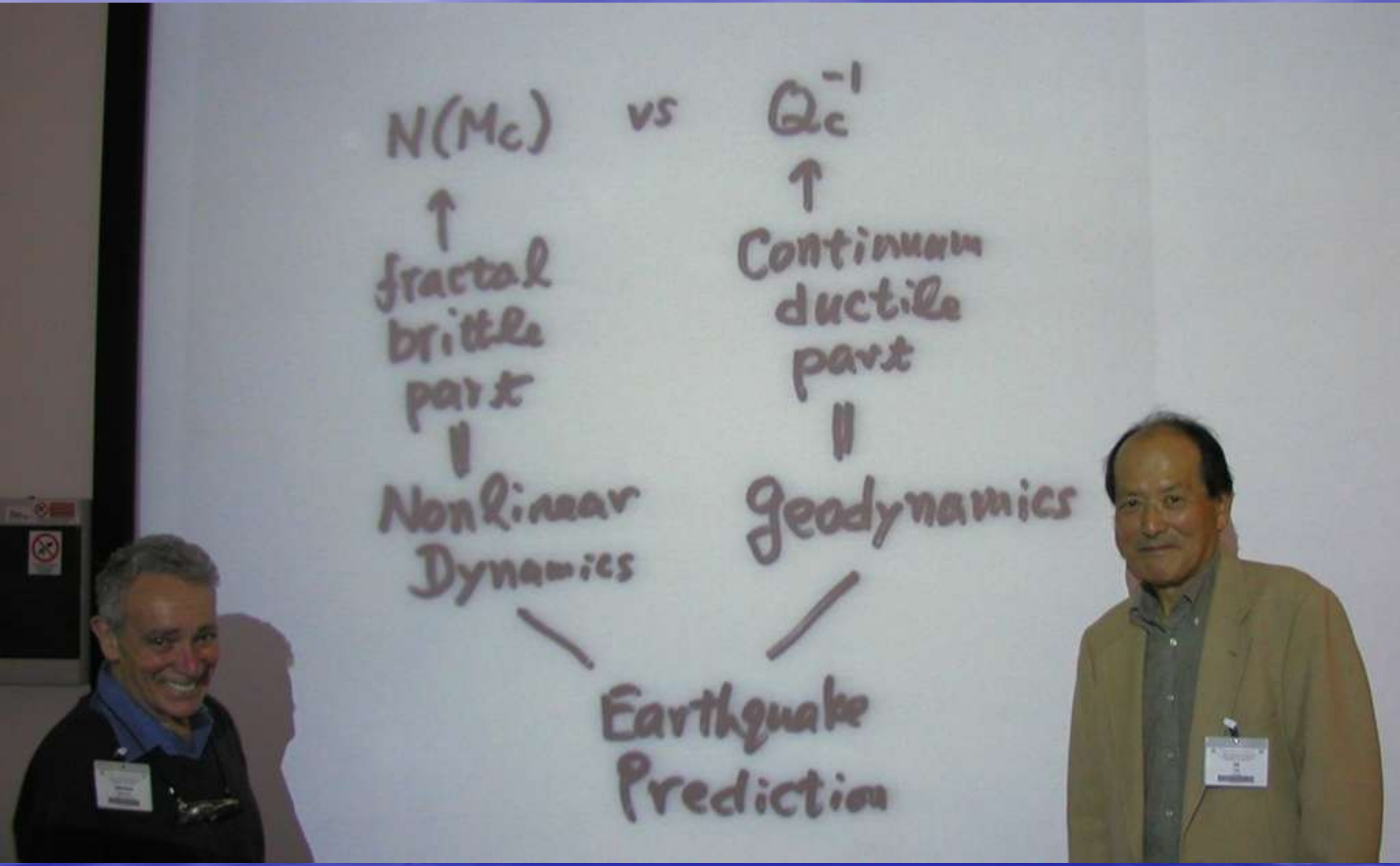
Kossobokov, V. G., Lepreti, F., Carbone, V.. Complexity in sequences of solar flares and earthquakes. *Pure Appl. Geophys.* **165** (2008) 761–775, DOI 10.1007/s00024-008-0330-z

- The statistics of inter-event times between earthquakes and solar flares show different scaling.
- **Even the same phenomenon when observed in different periods or at different spots of activity show different scaling. This difference were found in our analysis both for earthquakes and solar flares.**
- **The inter-event time distributions show a wide spectrum of the observed scaling that cannot be rescaled onto a single "universal" curve.**
- Even if some statistical analogies are present (e.g. power laws of different characteristics), which could be related to common characteristics of impulsive energy release processes in critical nonlinear systems, **our results do not support the presence of "universality".**

Are earthquakes predictable ?
YES.

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."


$N(M_c)$ vs Q_c^{-1}
fractal brittle part
Nonlinear Dynamics
Continuum ductile part
Geodynamics
Earthquake Prediction

"As Reagan later recalled for us over lunch, upstairs in his Swiss chateau, Gorbachev's experts gauged a two-thirds chance of an earthquake hitting 7.0 to 7.5 on the Richter scale, and the three fourths chance of a 6.0 to 6.5 earthquake before last November. The first forecast turned out to be more correct."

(San Francisco Chronicle, 26 October 1989)

OPEN FORUM / KEN ADELMAN

Quake Talk At the Summit

CAN YOU BELIEVE that Ronald Reagan and Mikhail Gorbachev discussed, at great length, the probability of a massive California earthquake during their very first encounter?

Well, they did. And somehow Gorbachev got it right. As recounted in "The Great Universal Embrace," my new book about Reagan administration adventures, we thought the topic most peculiar then. It still seems most peculiar now, but also prescient if not downright clairvoyant.

The timing was the end of November 1985. The setting was Geneva. The drama was high. This was the first U.S.-Soviet summit meeting in nearly seven years and the first ever for either Reagan or Gorbachev. President Reagan began his first session alone with the new Soviet leader by, well, just being Reagan. Rather than regurgitate the bureaucracy-furnished "talking points," he opened on a personal note.

The president told Gorbachev how odd life can be. For there they sat, he and Gorbachev, both of humble origins — born in small towns in the middle of nowhere — now, by a quirk of fate, the leaders of the two major world powers.

Gorbachev clearly warmed to the personal, genuine Reagan treatment. He then told how they must strive to overcome differences and build on what they shared. This led into his farsighted talk about the coming quake.

For Gorbachev then turned practical. Americans and Soviets, he told Reagan, could begin developing a better relationship by cooperating on scientific projects like, say, earthquake research. Before heading off to Geneva, in fact, Russian scientists had informed Gorbachev that California would definitely have an earthquake within about three years. That time frame expired only months before the big quake hit San Francisco and environs.

As Reagan later recalled for us over lunch, upstairs in his Swiss chateau, Gorbachev's experts gauged a two-thirds chance of an earthquake hitting 7.0 to 7.5 on the Richter scale, and a three-fourths chance of a 6.0 to 6.5 earthquake, before last November. The first forecast turned out more correct.

Gorbachev then offered to send Soviet scientists here to explain their conclusions and methods to their American counterparts. This kind offer was never accepted.

For at that time, American scientists were less alarmist. They figured only a 60 percent chance of a major earthquake over the next 30 years.

Nonetheless, Gorbachev had hit the right button. Not only did he turn out scientifically correct, but he proved a consummate diplomat by beginning to charm Reagan.

The president repeated for us the elaborate explanation he gave Gorbachev on the 750 mile-long San Andreas Fault. The former actor delivered this seemingly interminable set-piece for us, just as he had done for Gorbachev and for countless audiences before.

I watched Reagan's performance almost transfixed by its intensity and length. Meanwhile, the whole world was waiting and wondering what momentous issues the two most important individuals on Earth were discussing during their first encounter.

At the time, this seemed a massive diversion. Now, however, it seems more fitting.

Summits are, after all, meant to discuss the world's really big issues.

(Ken Adelman is former director of the Arms Control and Disarmament Agency.)

(available from *IASPEI Software Library, Vol. 6. Seismol. Soc. Am., El Cerrito, CA, 1997*)

M8 algorithm

This intermediate-term earthquake prediction method was designed by retroactive analysis of dynamics of seismic activity preceding the greatest, magnitude 8.0 or more, earthquakes worldwide, hence its name.

Its prototype (*Keilis-Borok and Kossobokov, 1984*) and the original version (*Keilis-Borok and Kossobokov, 1987*) were tested retroactively at 143 points, of which 132 are recorded epicenters of earthquakes of magnitude 8.0 or greater from 1857-1983.

The algorithm M8 uses traditional description of a dynamical system adding to a common phase space of rate (N) and rate differential (L) dimensionless concentration (Z) and a characteristic measure of clustering (B).

Second approximation prediction method MSc (*Mendocino Scenario*)

- The algorithm for reducing the area of alarm (*Kossobokov, Keilis-Borok, Smith, 1990*) was designed by retroactive analysis of the detailed regional seismic catalog prior to the Eureka earthquake (1980, M=7.2) near Cape Mendocino in California, hence its name abbreviated to MSc.
- Qualitatively, the MSc algorithm outlines such an area of the territory of alarm where the activity, from the beginning of seismic inverse cascade recognized by the first approximation prediction algorithm (e.g. by M8), is continuously high and infrequently drops for a short time. Such an alternation of activity must have a sufficient temporal and/or spatial span.
- The phenomenon, which is used in the MSc algorithm, might reflect the second (possibly, shorter-term and, definitely, narrow-range) stage of the premonitory rise of seismic activity near the incipient source of main shock.

- Prediction is aimed at earthquakes of magnitude M_0 and larger from the range $M_0+ = [M_0, M_0+\Delta M]$ (where $\Delta M < 1$). Magnitude scale should reflect the size of earthquake sources (accordingly, M_S or M_W usually taken for larger magnitudes, while mb is used for smaller ones).
- If the data permits, use different M_0+ with a step 0.5.
- Overlapping circles, with the diameter

  $D(M_0) = (exp(M_0 - 5.6)+1)^0$ in degrees of the Earth meridian, scan the seismic region under study.

M8 algorithm is applied first, then, if the data permits, the algorithm MSc provides a reduction of the TIPs' spatial uncertainty (although at the cost of additional failures-to-predict).

By 1992 all the components necessary for reproducible real-time prediction, i.e., an unambiguous definition of the algorithms and the data base, were specified in publications

- Algorithm M8 (*Keilis-Borok and Kossobokov, 1984, 1987, 1990*) was designed by retroactive analysis of seismic dynamics preceding the greatest ($M \geq 8$) earthquakes worldwide, as well as the MSc algorithm for reducing the area of alarm (*Kossobokov,Keilis-Borok, Smith, 1990*)
- The National Earthquake Information Center Global Hypocenters Data Base (*US GS/NEIC GHDB, 1989*) is sufficiently complete since 1963.
- This allowed a systematic application of M8 and MSc algorithm since 1985.

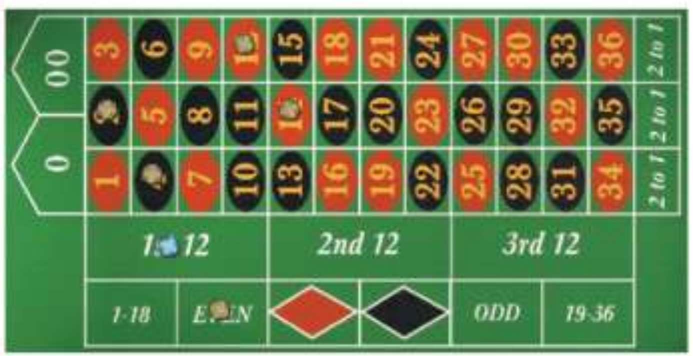
Real-time prediction of the world largest earthquakes: An experiment started in 1992 with a publication of

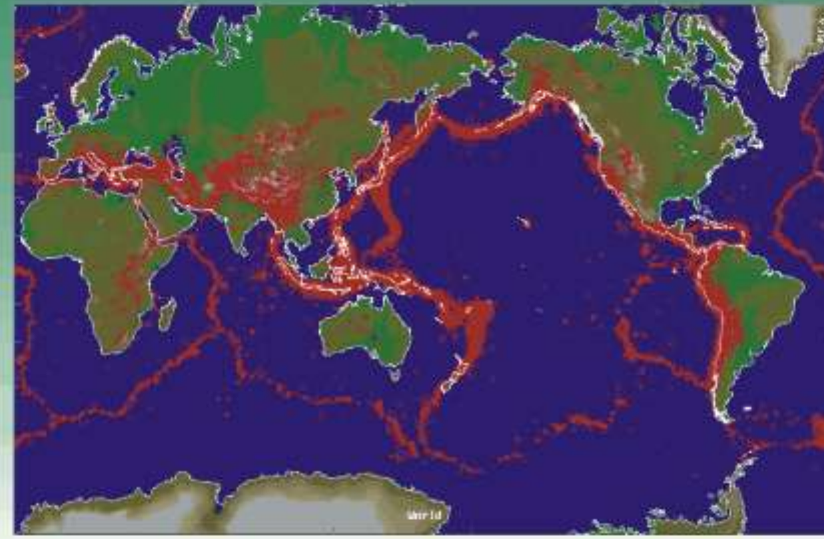
[Healy, J. H., V. G. Kossobokov, and J. W. Dewey. A test to evaluate the earthquake prediction algorithm, M8, *U.S. Geol. Surv. Open-File Report* **92-401**, 23 p. with 6 Appendices, 1992]

is going on.

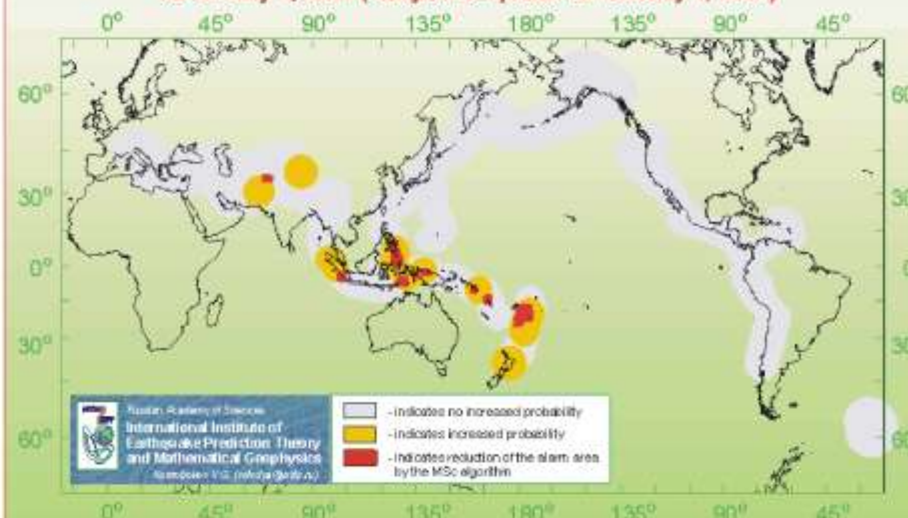
Although the M8-MSc predictions are intermediate-term middle-range and by no means imply any "red alert", some colleagues have expressed a legitimate concern about maintaining necessary confidentiality. Therefore, the up-to-date predictions are not easily accessed, although available on the web-pages of restricted access provided to about 150 members of the Mailing List.

SEISMIC ROULETTE





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



Seismic Roulette null-hypothesis

Consider a roulette wheel with as many sectors as the number of events in a sample catalog, a sector per each 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! ☺ ☺ ☹ ☺ ☺ ☺ ☹ ☺ ☺ ☺

Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 8.0+.

Test period	Target earthquakes: Total	Predicted by M8	Predicted by M8-MSc	Measure of alarms, %: M8	Measure of alarms, %: M8-MSc	Confidence level, %: M8	Confidence level, %: M8-MSc
1985-present	19	14	10	33.16	16.89	99.96	99.96
1992-present	17	12	8	30.09	15.04	99.93	99.82

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

To drive the achieved confidence level below 95%, the Test should encounter nine failures-to-predict in a row.

Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 7.5 or more.

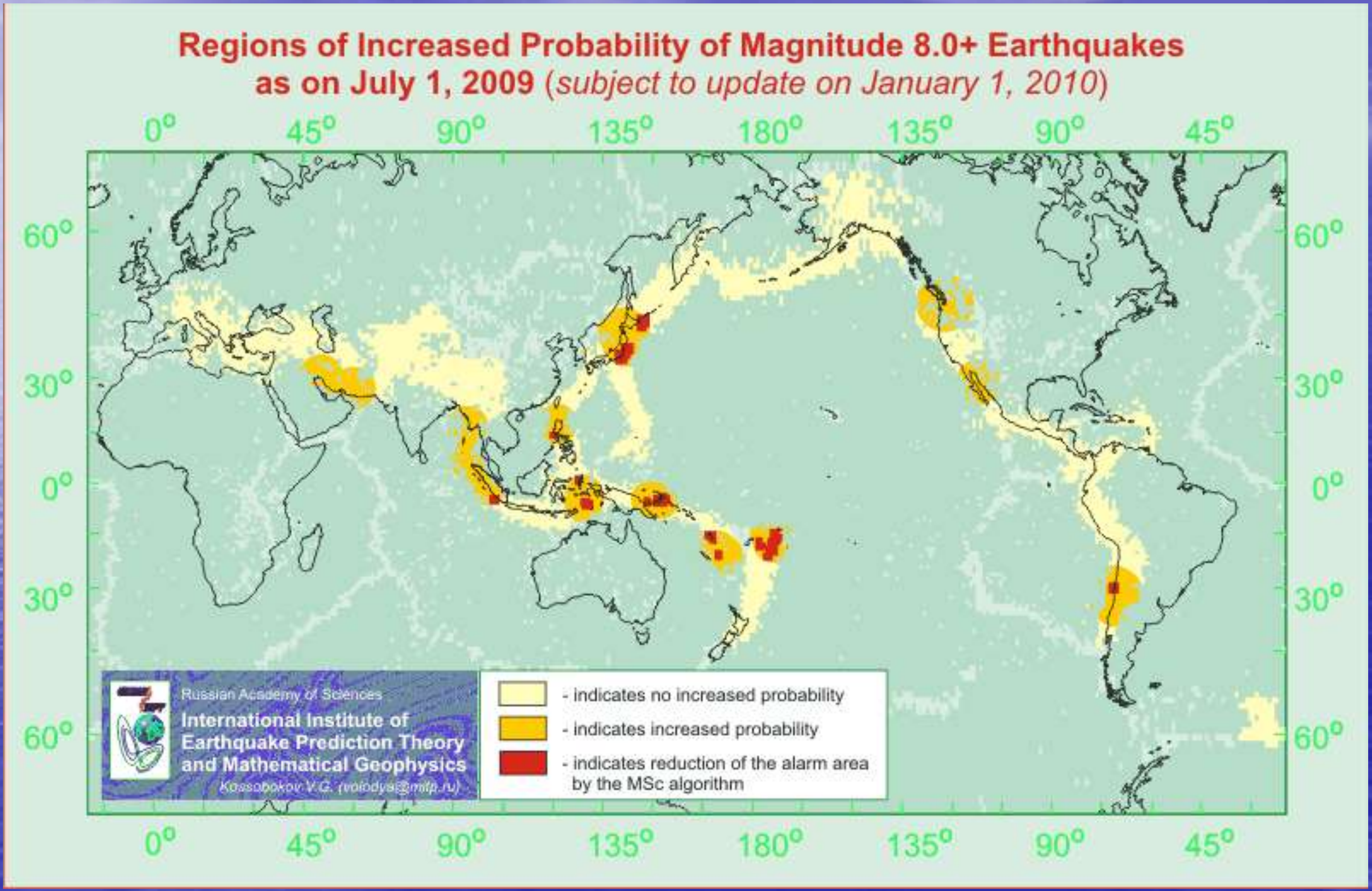
Test period	Target earthquakes			Measure of alarms,%		Confidence level, %	
	Total	Predicted by					
		M8	M8-MSc	M8	M8-MSc	M8	M8-MSc
1985-present	65	38	16	28.73	9.32	99.99	99.98
1992-present	53	28	10	23.14	8.31	99.99	98.89

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

To drive the achieved confidence level below 95%, the Test should encounter 15(!) failures-to-predict in a row.

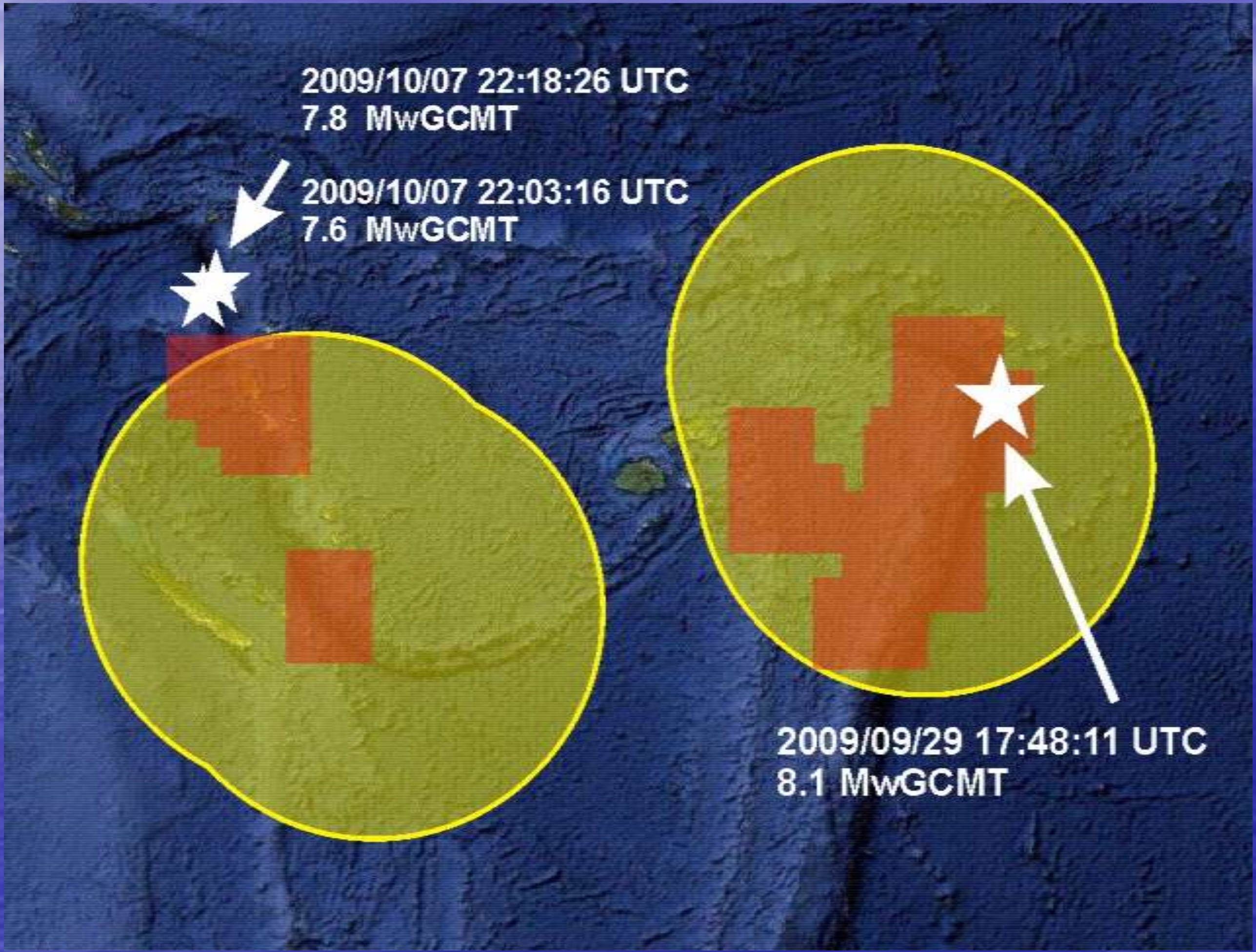
Real-time prediction of the world largest earthquakes

(http://www.mitp.ru)

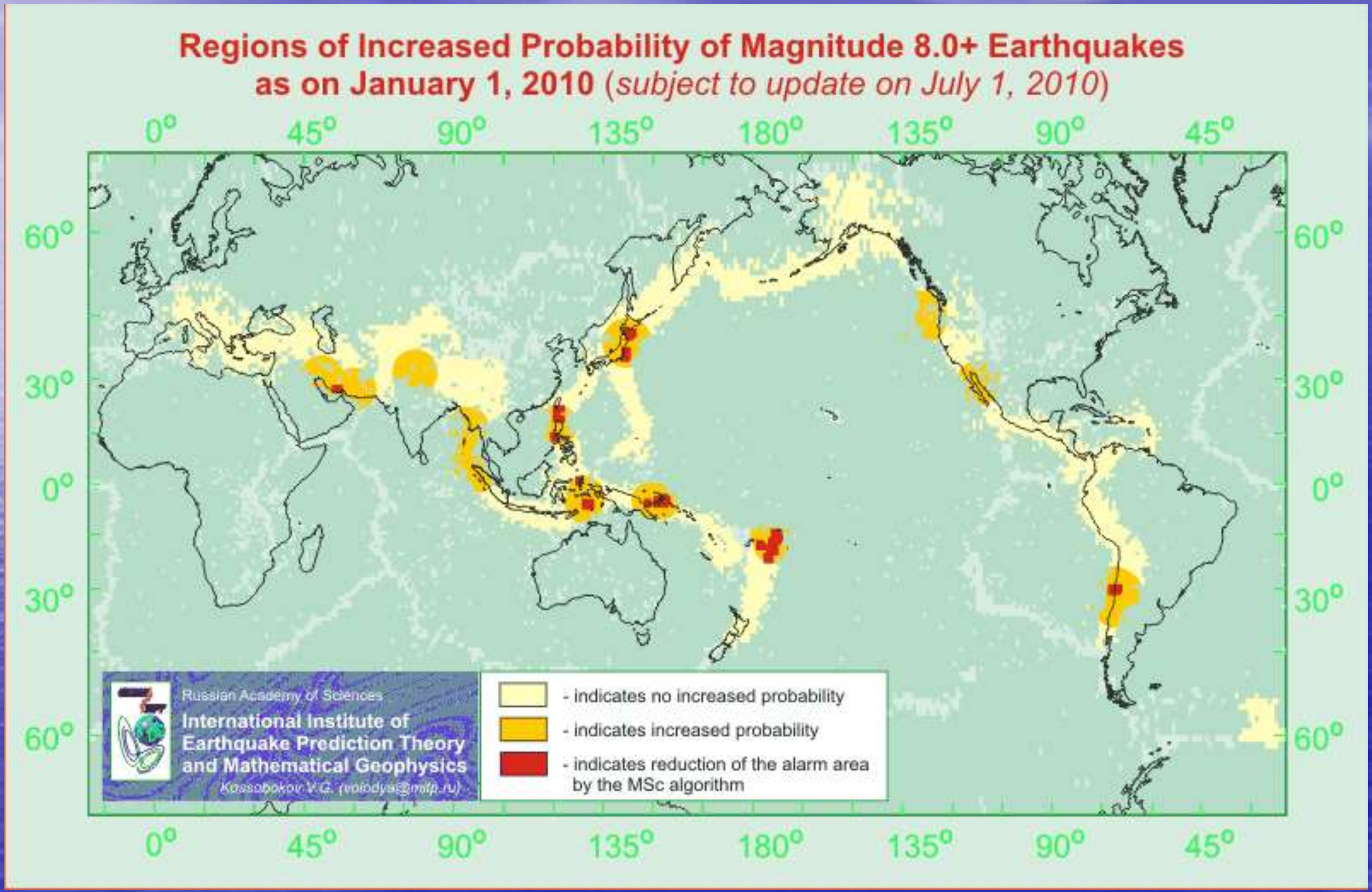


Real-time prediction of the world largest earthquakes

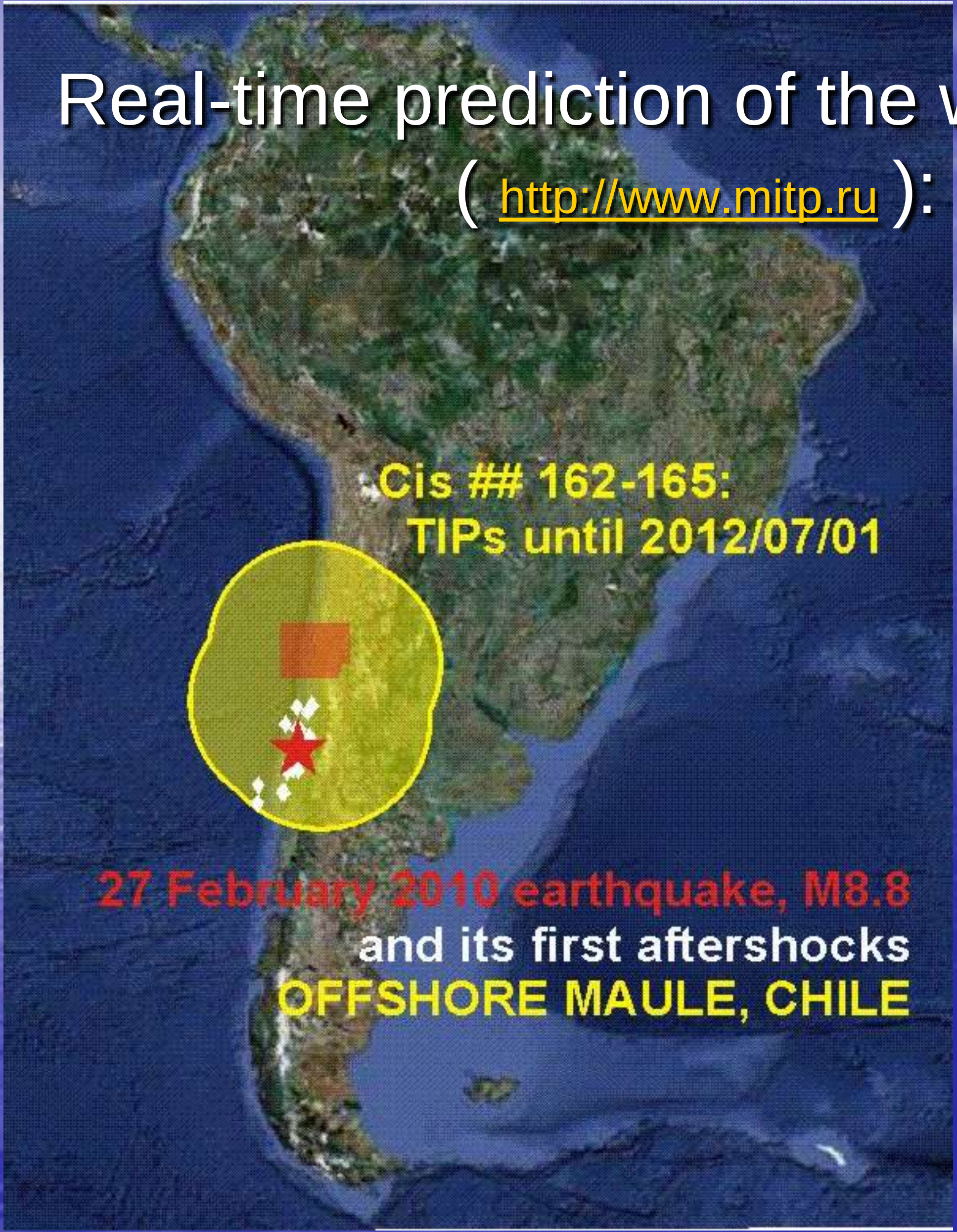
(http://www.mitp.ru)



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



Real-time prediction of the world largest earthquakes (http://www.mitp.ru): Magnitude 8.0+.

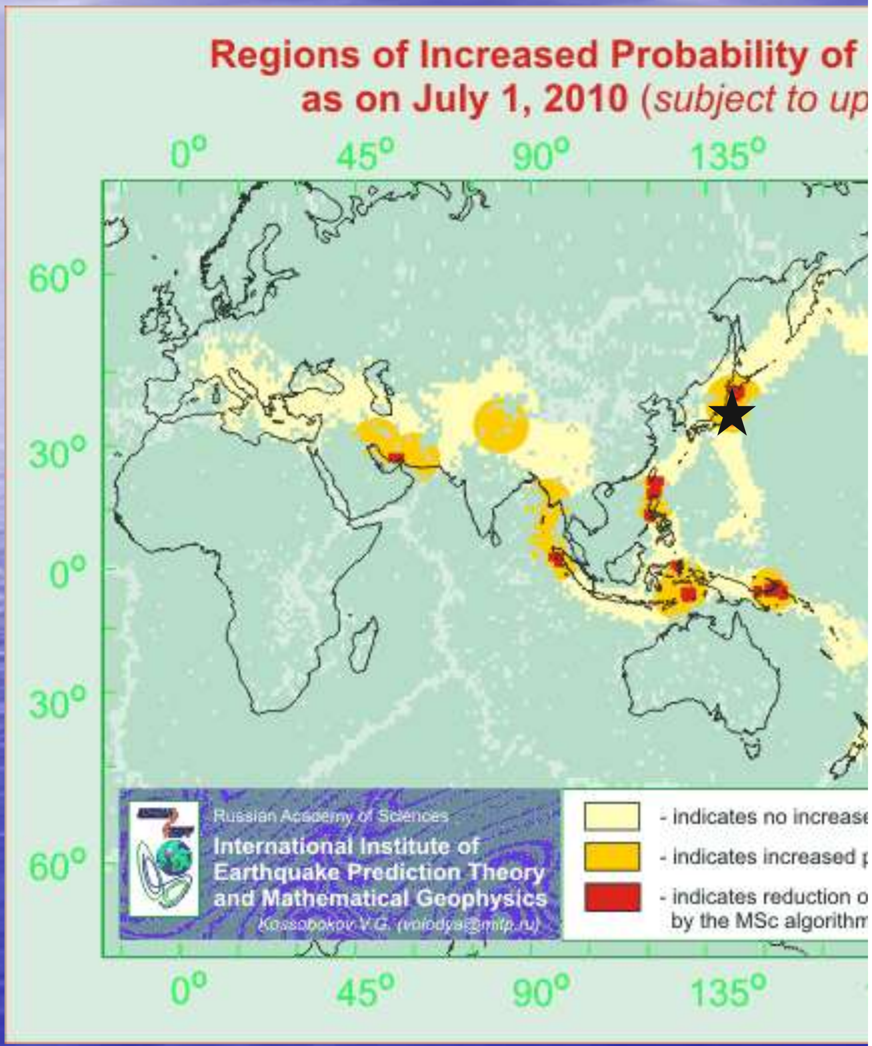


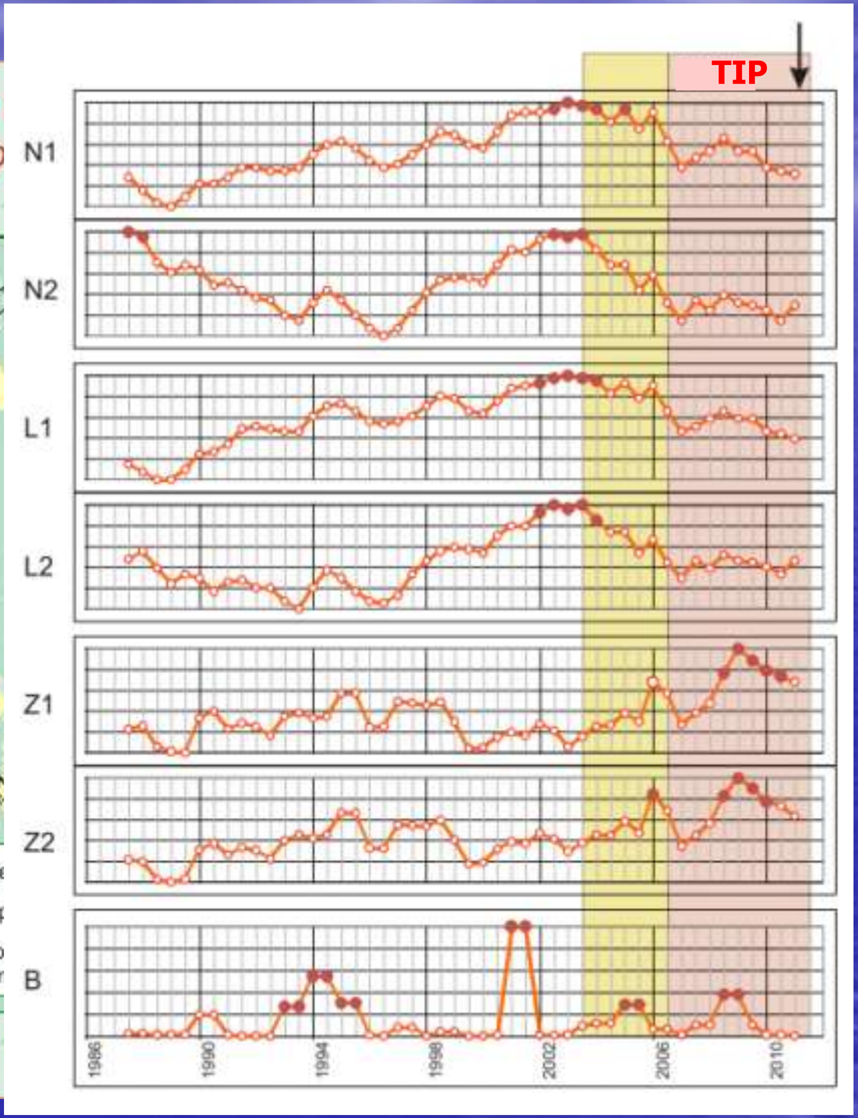
The 27 February 2010 mega-earthquake OFFSHORE MAULE, CHILE has ruptured the 600-km portion of the South American subduction zone, which was recognized (yellow outline) as capable of producing a magnitude M8.0+ event before mid-2012 in the regular 2010a Update. The earthquake epicenter missed the reduced area of alarm (red outline) diagnosed in the second approximation by algorithm MSc.

The failure of MSc algorithm is somewhat natural, taking into account the linear extent of the event, which is about a half of the area alerted in the first approximation.

Real-time prediction of the world largest earthquakes

(http://www.mitp.ru or http://www.phys.ualberta.ca/mirrors/mitp)

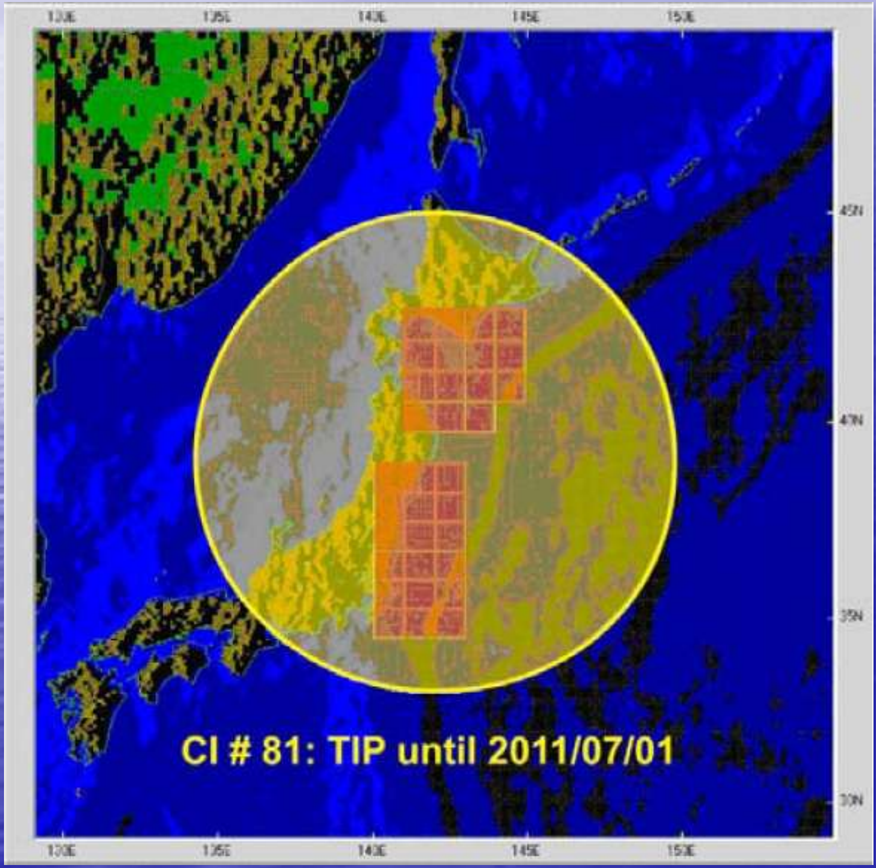


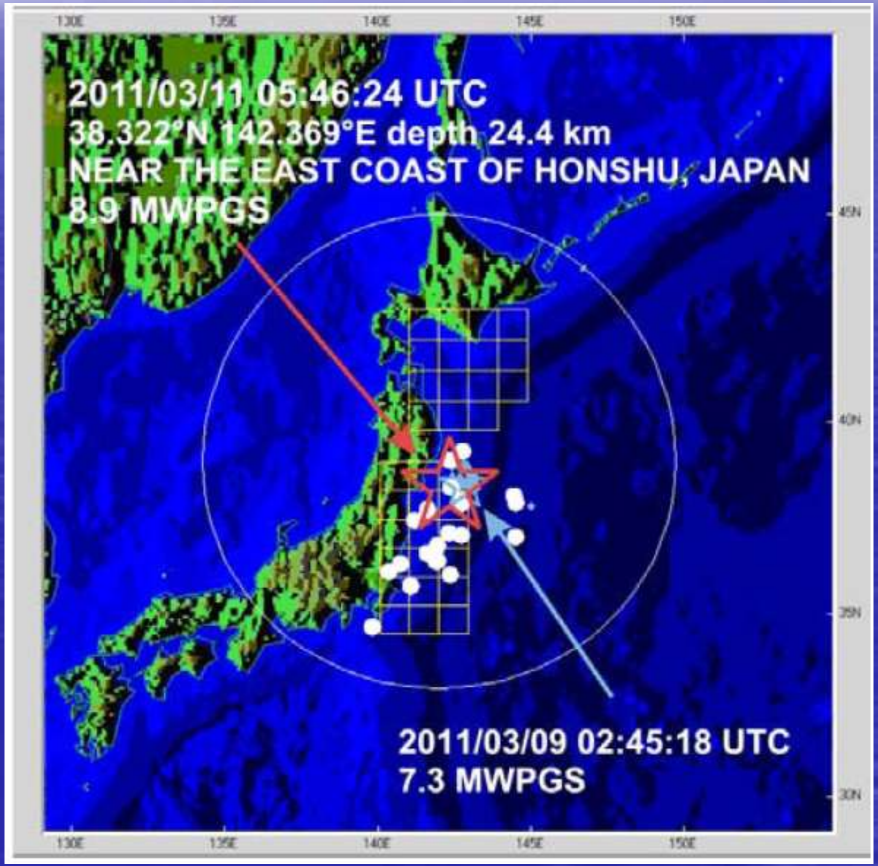


Real-time prediction of the world largest earthquakes

(http://www.mitp.ru)

The 11 March 2011 MwGCMT 9.0 Tōhoku mega-thrust –
the 2011 Great East Japan Earthquake

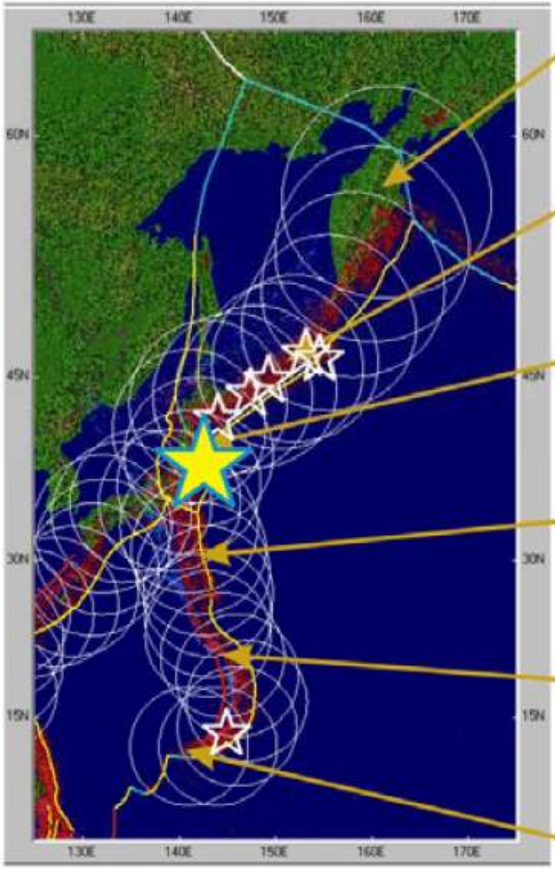


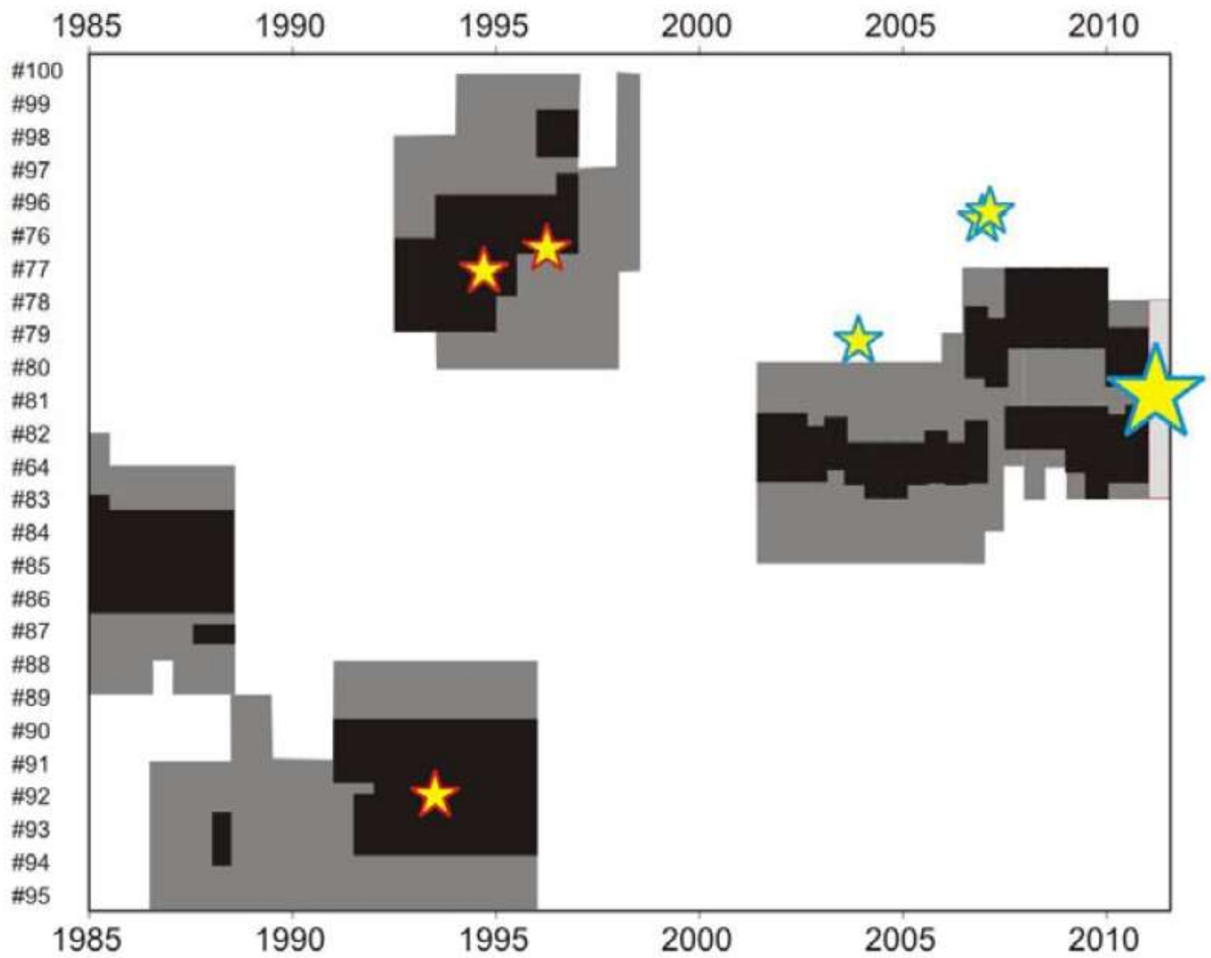


Space-time history of M8-MSc predictions in West Pacific

Space

Time





ГЕОФИЗИЧЕСКИЕ ПРОЦЕССЫ И БИОСФЕРА, 2011, Т. 10, № 2, с. 5–21

ARE MEGA EARTHQUAKES PREDICTABLE?

V.G. Kossobokov[1,2]

[1] International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russia
[2] Institut de Physique du Globe de Paris, Paris, France

Abstract. In the course of the ongoing since 1992 Global Test of the intermediate-term middle-range earthquake forecast/predictions by the algorithms M8 and MSc place and time of each of the mega-earthquakes of 27 February 2010 in Chile and 11 March 2011 in Japan were recognized as in state of increased probability of such events in advance their occurrences. In conjunction with a retrospective analysis of seismic activity preceding the first of a series of mega earthquakes of the 21st century, i.e. 26 December 2004 in the Indian Ocean, these evidences give grounds for assuming that the algorithms of proven validated effectiveness in magnitude ranges *M*7.5+ and *M*8.0+ can be applied to predict the mega-earthquakes as well.

Keywords: earthquake, mega earthquake, forecast, prediction, algorithm, statistical hypothesis testing, random guessing, confidence level.

First conclusions on predictability of mega-earthquakes reported in 2005:

"Since good evidence suggests that mega-earthquakes as other seismic events cluster, it is likely that we shall evidence further confirmations of the prediction within 5-10 years."

Kossobokov, V.G., 2005. 26 December 2004 Greatest Asian Quake: When to expect the next one? *Statement at Special Session on the Indian Ocean Disaster: risk reduction for a safer future*. UN World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, JAPAN.

Further confirmations expected…

Conclusions – The Four Paradigms

Statistical validity of predictions demonstrated in 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

(Keilis-Borok, Gabrielov, and Soloviev, 2009;

Keilis-Borok,Soloviev, and Lichtman, 2009).

Conclusions – Seismic Roulette is not perfect

- The accuracy of the M8-MSc predictions 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 (*Molchan, 1997*).

General Conclusions

Based on the recent, enormous progress in real-time retrieval and monitoring of distributed multitude of geophysical data -

- Contemporary Science can do a better job in disclosing Natural **Hazards**, assessing **Risks**, and delivering such info in advance catastrophic events.
- Geoscientists must initiate shifting the minds of community from pessimistic disbelieve to optimistic challenging issues of **Hazard Predictability**

Thank you!