Predictability of Seismic Extremes

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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 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.
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...endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction...
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
Each of 1181 strong crustal earthquakes in 2000-2009 has from 6 to 58 values of GSHAP PGA in the $\frac{1}{4}^\circ \times (1/4\cos\phi)^\circ$ cell centered at its epicenter $(\phi, \lambda)$.

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 $\Delta I_0$, and the median of $\Delta I_0$ 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 $\Delta I_0$ is 0.6, while the average and the median of $\Delta I_0$ are about 2.
<table>
<thead>
<tr>
<th>Region</th>
<th>Date</th>
<th>$M$</th>
<th>Fatalities</th>
<th>$\Delta I_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumatra-Andaman “Indian Ocean Disaster”</td>
<td>26.12.2004</td>
<td>9.0</td>
<td>227898</td>
<td>4.0</td>
</tr>
<tr>
<td>Port-au-Prince (Haiti)</td>
<td>12.01.2010</td>
<td>7.3</td>
<td>222570</td>
<td>2.2</td>
</tr>
<tr>
<td>Wenchuan (Sichuan, China)</td>
<td>12.05.2008</td>
<td>8.1</td>
<td>87587</td>
<td>3.2</td>
</tr>
<tr>
<td>Kashmir (North India and Pakistan border region)</td>
<td>08.10.2005</td>
<td>7.7</td>
<td>~86000</td>
<td>2.3</td>
</tr>
<tr>
<td>Bam (Iran)</td>
<td>26.12.2003</td>
<td>6.6</td>
<td>~31000</td>
<td>0.2</td>
</tr>
<tr>
<td>Bhuj (Gujarat, India)</td>
<td>26.01.2001</td>
<td>8.0</td>
<td>20085</td>
<td>2.9</td>
</tr>
<tr>
<td>Off the Pacific coast of Tōhoku (Japan)</td>
<td>11.03.2011</td>
<td>9.0</td>
<td>15477 (7464 missing)</td>
<td>3.2</td>
</tr>
<tr>
<td>Yogyakarta (Java, Indonesia)</td>
<td>26.05.2006</td>
<td>6.3</td>
<td>5749</td>
<td>0.3</td>
</tr>
<tr>
<td>Southern Qinghai (China)</td>
<td>13.04.2010</td>
<td>7.0</td>
<td>2698</td>
<td>2.1</td>
</tr>
<tr>
<td>Boumerdes (Algeria)</td>
<td>21.05.2003</td>
<td>6.8</td>
<td>2266</td>
<td>2.1</td>
</tr>
<tr>
<td>Nias (Sumatra, Indonesia)</td>
<td>28.03.2005</td>
<td>8.6</td>
<td>1313</td>
<td>3.3</td>
</tr>
<tr>
<td>Padang (Southern Sumatra, Indonesia)</td>
<td>30.09.2009</td>
<td>7.5</td>
<td>1117</td>
<td>1.8</td>
</tr>
</tbody>
</table>
The contributors to GSHAP could have evaluate the poor performance of their product before its publication in 1999...

<table>
<thead>
<tr>
<th>Total</th>
<th>( \Delta I_0 = I_0(M) - I_0(mPGA) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>&gt; 0</td>
<td>&gt; 1</td>
</tr>
</tbody>
</table>

**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  |

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>
<thead>
<tr>
<th>Earthquake</th>
<th>Expected PGA (g) with a probability of exceedance of 10% in 50 years (return period 475 years)</th>
<th>Observed PGA (g)</th>
<th>Computed DGA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobe</td>
<td>0.40–0.48</td>
<td>0.7–0.8</td>
<td></td>
</tr>
<tr>
<td>Gujarat</td>
<td>0.16–0.24</td>
<td>0.5–0.6</td>
<td>0.3–0.6</td>
</tr>
<tr>
<td>Boumerdes</td>
<td>0.08–0.16</td>
<td>0.3–0.4*</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>Bam</td>
<td>0.16–0.24</td>
<td>0.7–0.8</td>
<td></td>
</tr>
<tr>
<td>Eastern Sichuan</td>
<td>0.16–0.24</td>
<td>0.6–&gt;0.8 (Shakemap)</td>
<td></td>
</tr>
<tr>
<td>Haiti</td>
<td>0.08–0.16</td>
<td>0.3–0.6*</td>
<td></td>
</tr>
</tbody>
</table>
The color coded discrepancy, $\Delta I_0$, 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 website with forecasts of expected ground shaking for ‘tomorrow’ and Nature published the underlying work by Gerstenberger et al.

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 Kolmogorov-Smirnov 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 $D = \max | F_{\text{green}}(t) - F_{\text{red}}(t) | \cdot (N_1 N_2/(N_1 + N_2))^{1/2} \geq 2.12$) 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 -
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...).

WHAT DO YOU WANT TO BE WHEN YOU GROW UP, DAJAEE?

A PRE-CONCEPTUAL SCIENTIST

UP... 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 THE DUMBEST THING I HEARD... DISMISSED...
...So as a pre-conceptual scientist, you reach a conclusion to a theory first, then just ignore all evidence that proves you're wrong?

Yes.

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...

[Character 3: Lala-lala-lala-lala]

I give up...

See how easy it is?


Hans Christian Andersen, 1837. Keiserens nye Klæder
“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.”

Izrail Moiseevich Gelfand
(1913-2009)
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. Sadovskiy

Садовский М.А., Болховитинов Л.Г., Писаренко В.Ф., 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 \( L \).
The Global Seismic Hazard map: Coefficient B

Magnitude balance relation

B

0.5 0.7 0.9 1.1 1.3

(magnitude unit)^{-1}
The Global Seismic Hazard map: Coefficient C

Fractal dimension of seismic locus

C

0.5  0.75  1.0  1.25  1.5

dimensionless
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.


JMA earthquake catalog, 1980-2002
maximum $I_0$, 10% chance in 50 years.
Top magnitude earthquakes cluster in time

Year
Magnitude


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<table>
<thead>
<tr>
<th>Location</th>
<th>Date UTC</th>
<th>Magnitude</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.Kamchatka</td>
<td>4-Nov-1952</td>
<td>9.0</td>
<td>52.76 N</td>
<td>160.06 E</td>
</tr>
<tr>
<td>4.Andreanof Islands, Alaska</td>
<td>9-Mar-1957</td>
<td>9.1</td>
<td>51.56 N</td>
<td>175.39 W</td>
</tr>
<tr>
<td>1.Chile</td>
<td>22-May-1960</td>
<td>9.5</td>
<td>38.24 S</td>
<td>73.05 W</td>
</tr>
<tr>
<td>2.Off the West Coast of Northern Sumatra</td>
<td>26-Dec-2004</td>
<td>9.3</td>
<td>3.30 N</td>
<td>95.78 E</td>
</tr>
</tbody>
</table>

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

![Graph showing distribution of earthquakes in space and time.](image)

**Time**

- 01/01/85
- 01/01/95
- 01/01/05

**Distance, km**

- 0
- 500
- 1000
- 1500
- 2000
- -500
- -1000

**Distance, km**

- 0
- 500
- 1000
- 1500
- 2000
- -500
- -1000

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

Distance, km

Time

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

Distance, km

Time

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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


- 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 \( \alpha \) fitting constants.

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

<table>
<thead>
<tr>
<th></th>
<th>Flares</th>
<th>Flares at spot</th>
<th>SCSN</th>
<th>Landers</th>
<th>SGR1806-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flares</td>
<td>32076</td>
<td>3.435</td>
<td>8.648</td>
<td>2.071</td>
<td>0.636</td>
</tr>
<tr>
<td>Flares at spot</td>
<td>100 %</td>
<td>18878</td>
<td>5.898</td>
<td>1.669</td>
<td>0.434</td>
</tr>
<tr>
<td>SCSN</td>
<td>100 %</td>
<td>100 %</td>
<td>87688</td>
<td>3.720</td>
<td>1.435</td>
</tr>
<tr>
<td>Landers</td>
<td>99.96%</td>
<td>99.26%</td>
<td>100 %</td>
<td>10706</td>
<td>0.47</td>
</tr>
<tr>
<td>SGR1806-20</td>
<td>19.13%</td>
<td>0.92%</td>
<td>96.77%</td>
<td>2.24%</td>
<td>110</td>
</tr>
</tbody>
</table>

- 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

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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."
“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)
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

$$D(M_0) = \left( \exp(M_0 - 5.6) + 1 \right)^0$$

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≥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
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+.

<table>
<thead>
<tr>
<th>Test period</th>
<th>Target earthquakes</th>
<th>Measure of alarms, %</th>
<th>Confidence level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Predicted by M8</td>
<td>Predicted by M8-MSc</td>
</tr>
<tr>
<td>1985-2011</td>
<td>19</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>1992-present</td>
<td>17</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Test period</th>
<th>Target earthquakes</th>
<th>Measure of alarms, %</th>
<th>Confidence level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Predicted by</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M8</td>
<td>M8-MSc</td>
</tr>
<tr>
<td>1992-present</td>
<td>53</td>
<td>28</td>
<td>10</td>
</tr>
</tbody>
</table>

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)

Regions of Increased Probability of Magnitude 8.0+ Earthquakes
as on July 1, 2009 (subject to update on January 1, 2010)
Real-time prediction of the world largest earthquakes

(http://www.mitp.ru)

2009/10/07 22:18:26 UTC
7.8 MwGCMT

2009/10/07 22:03:16 UTC
7.6 MwGCMT

2009/09/29 17:48:11 UTC
8.1 MwGCMT
Real-time prediction of the world largest earthquakes

(http://www.mitp.ru)

Regions of Increased Probability of Magnitude 8.0+ Earthquakes
as on January 1, 2010 (subject to update on July 1, 2010)

Thursday, 30 June 2011 • XXV IUGG General Assembly • Melbourne, Australia, 28 June - 7 July 2011 •
MR211 • 16:30 - 17:00
Melbourne Convention Centre
Real-time prediction of the world largest earthquakes

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)

Regions of Increased Probability of

as on July 1, 2010 (subject to update)

- indicates no increase
- indicates increased
- indicates reduction

by the MSc algorithm

TIP
Real-time prediction of the world largest earthquakes

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

Thursday, 30 June 2011 ♦ XXV IUGG General Assembly ♦ Melbourne, Australia, 28 June - 7 July 2011 ♦
MR211 ♦ 16:30 - 17:00
Melbourne Convention Centre
ARE MEGA EARTHQUAKES PREDICTABLE?

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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 $M7.5+$ and $M8.0+$ 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.”


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!