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Earthquake Hazard Assessment: an Independent Review

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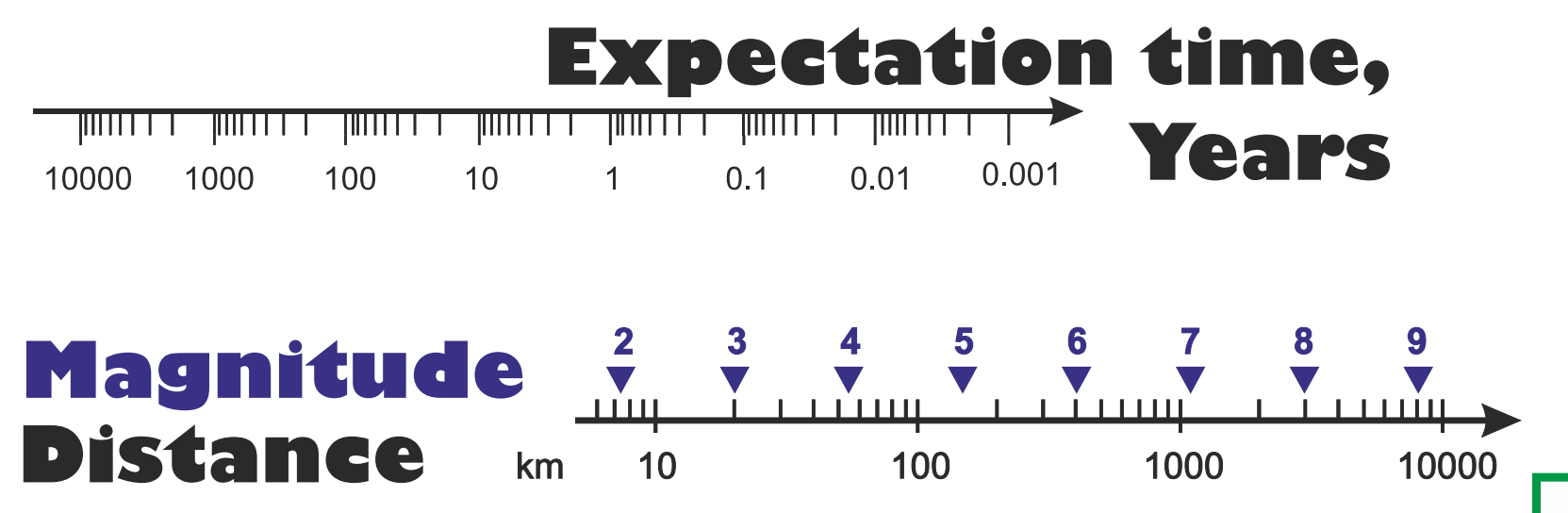
Seismic hazard assessment (SHA), from term-less (probabilistic PSHA or deterministic DSHA) to time-dependent (t-DASH) including short-term earthquake forecast/prediction (StEF), is not an easy task that implies a delicate application of statistics to data of limited size and different accuracy. Regretfully, in many cases of SHA, t-DASH, and StEF, the claims of a high potential and efficiency of the methodology are based on a flawed application of statistics and hardly suitable for communication to decision makers. 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, is evident, and such a testing must be done in advance claiming hazardous areas and/or times. 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 may supply 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.

These basics of SHA evaluation are exemplified with examples of misleading "seismic hazard maps", "precursors", and "forecast/prediction methods".

Basics

Natural scaling for seismic processes



The linear dimensions of the target earthquake preparation zone R = $10^{0.43\,M}$ km (*Dobrovolsky et al., 1979*) [$\log_{10} e = 0.434\ldots$]

Natural accuracy

Prediction of time and location of an earthquake of a certain magnitude range can be classified into the categories below –

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

Note that a wide variety of possible combinations that exist is much larger than the usually considered "short-term exact" one. In principle, such an accurate statement about anticipated seismic extreme might be futile due to the complexities of the Earth's lithosphere, its blocks-and-faults structure, and evidently nonlinear dynamics of the seismic process. The observed scaling of source size and preparation zone with earthquake magnitude implies exponential scales for territorial accuracy of predictions similar to the temporal ones. Naturally, the spatial accuracy of prediction is linked to the source zone linear dimension, l. It varies from exact pinpointing the source to long-range uncertainty of about a few tens of l.

One may compare the intermediate-term accuracy of earthquake forecast/prediction in time to the next day warning of a coming hurricane, while the middle-range accuracy in location to shooting 8 or more points by an air-pistol from 10 meters. This kind of accuracy is proved achievable and reliable in the two decades of rigid real-time testing the M8 algorithm (Kossobokov, 2013, 2014).

Earthquake prediction definition

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

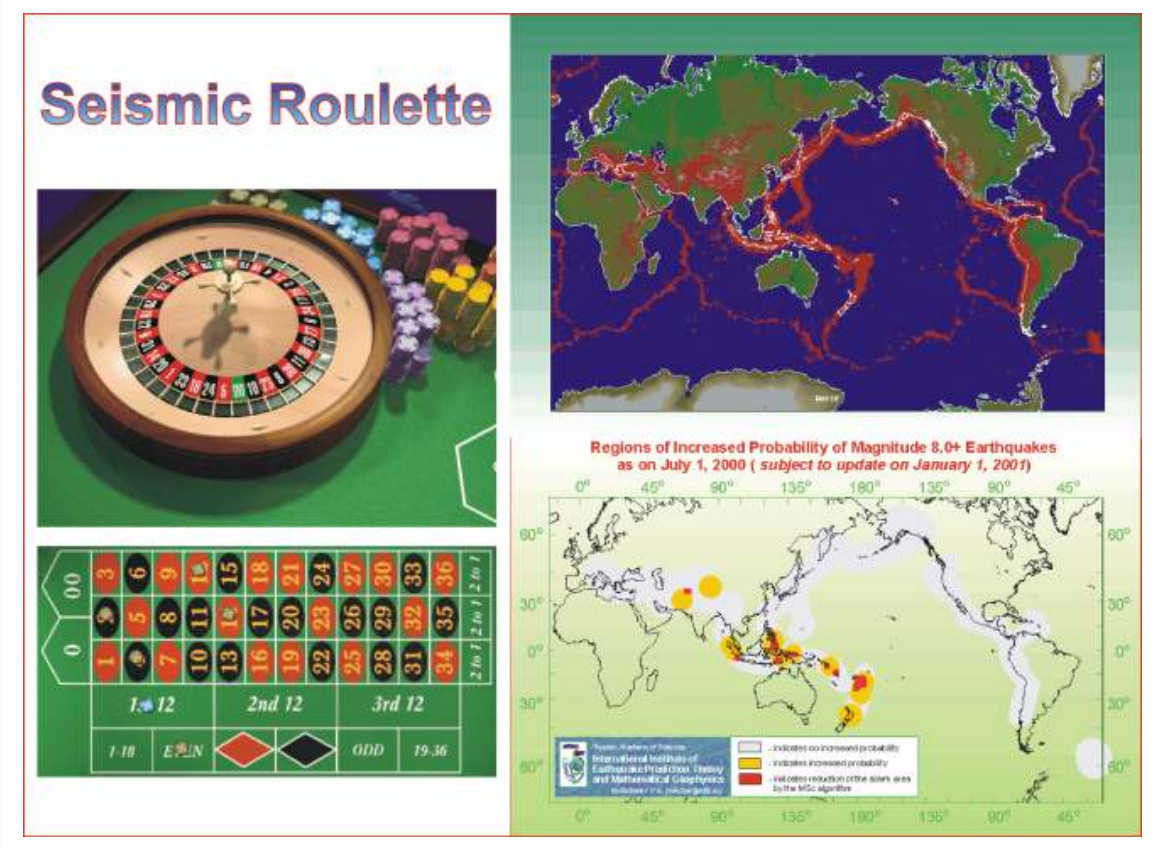
"An earthquake prediction must specify the expected magnitude range, the geographical area within which it will occur, and the time interval within which it will happen with sufficient precision so that the ultimate success or failure of the prediction can readily be judged. Only by careful recording 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."

Natural seismic volume

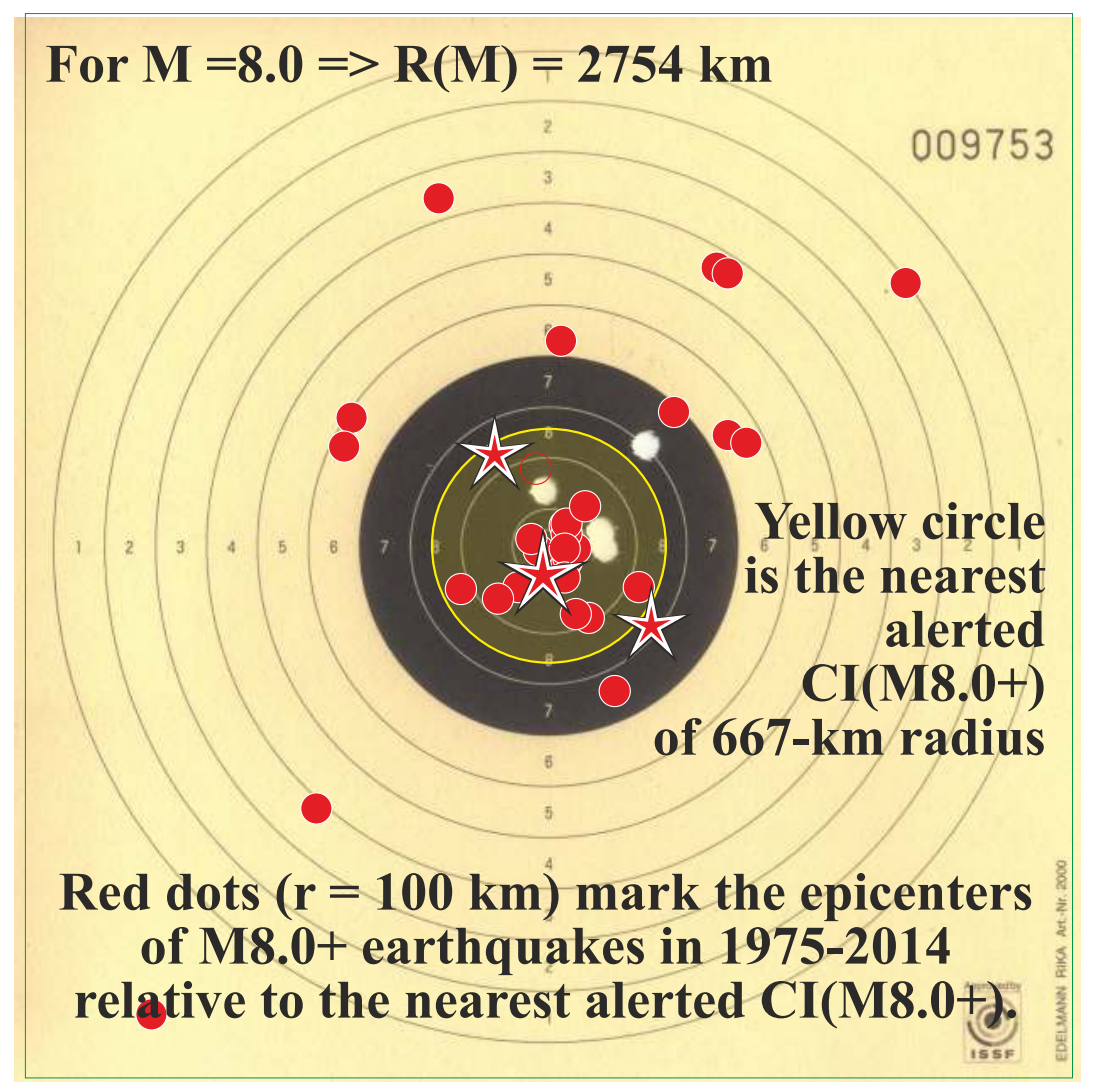
Seismic Roulette: Consider a roulette wheel with as many sectors as the number of events in your sample earthquake catalog, a sector for each event. Make your bet according to prediction: determine which events are inside area of alarm, and put one chip in each of the corresponding sectors. Nature turns the wheel.

If seismic roulette is not perfect, one can win systematically. This may require a switch from the original algorithm that loses systematically to its "antipodal" version (Molchan, 1994; 2003).

Seismic Roulette



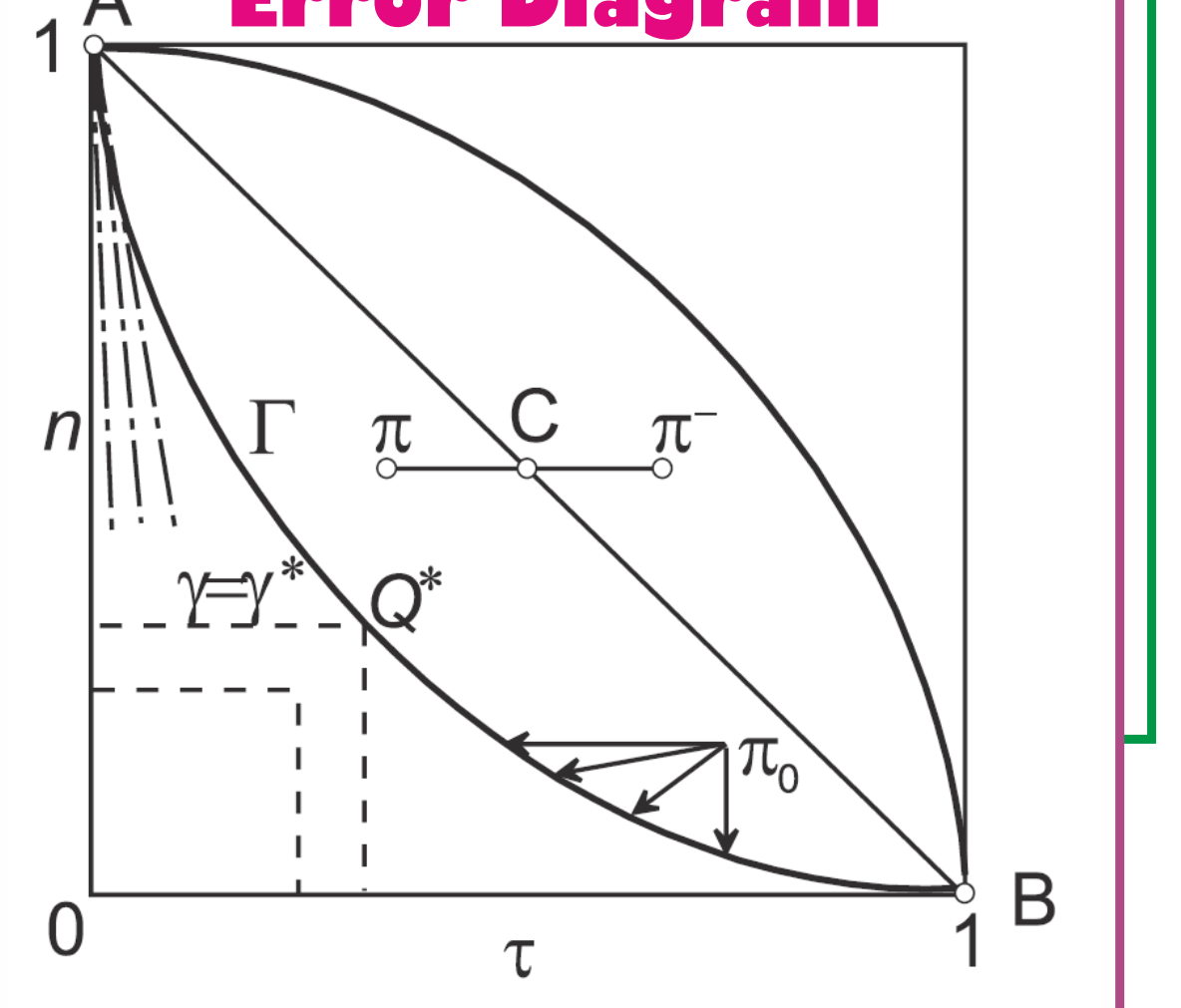
For M =8.0 => R(M) = 2754 km



Yellow circle is the nearest alerted CI(M8.0+) of 667-km radius

Red dots (r = 100 km) mark the epicenters of M8.0+ earthquakes in 1975-2014 relative to the nearest alerted CI(M8.0+).

Error Diagram

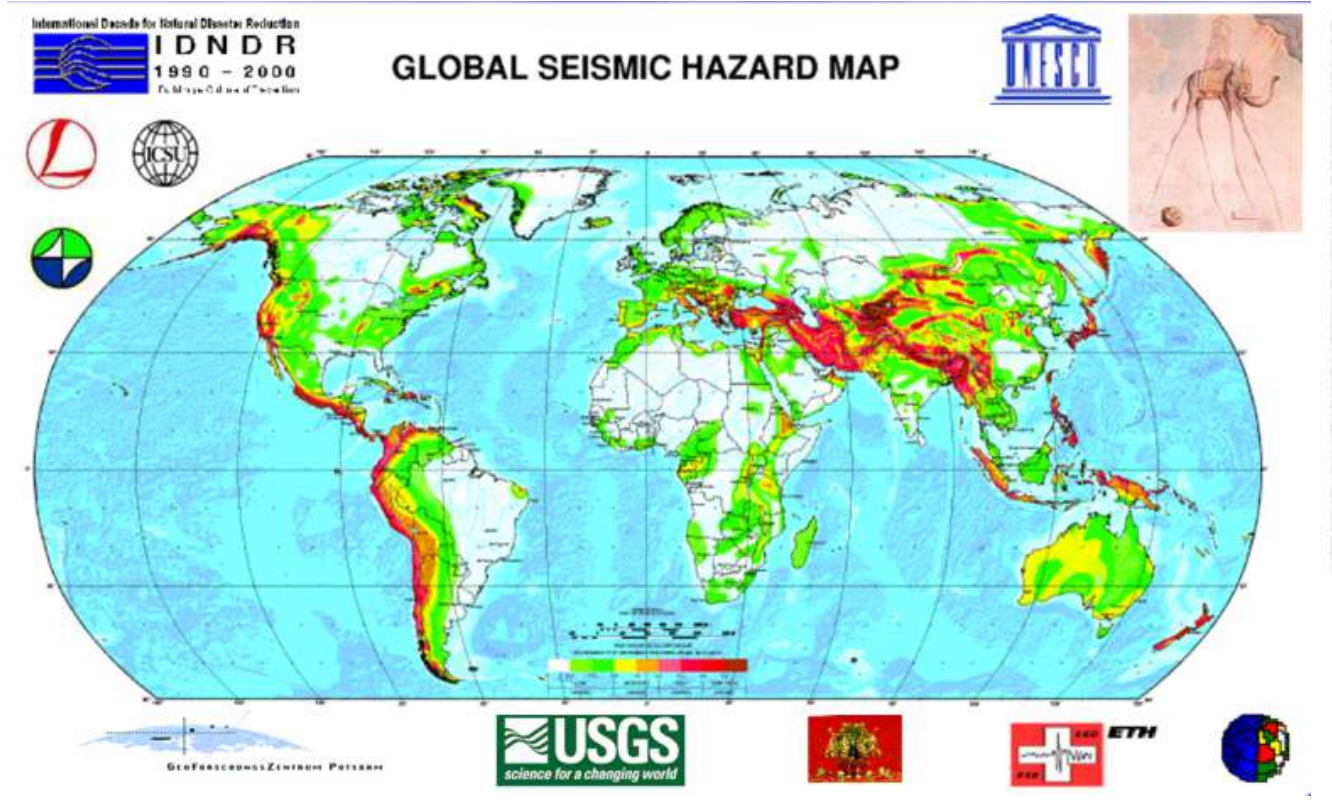


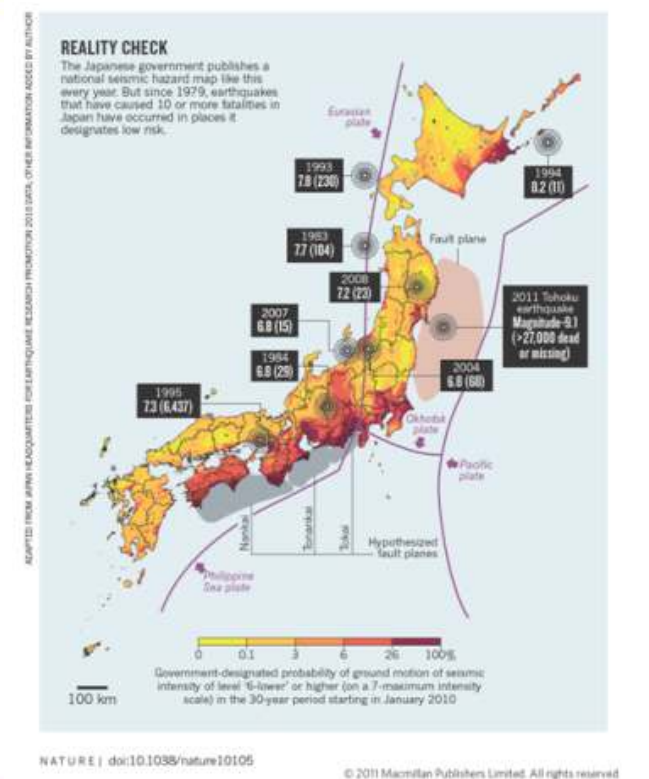
Any point (n, τ) inside [0,1]×[0,1] corresponds to n failures achieved in alarm time τ. Naturally, forecasts based on limited information fill just a part of [0,1]×[0,1]. Point A corresponds to optimistic strategy (no alarm – total failure), point B to pessimistic strategy (full time alarm – no failure), the diagonal AB corresponds to strategies of random guessing with (1 − n) = τ; C = (½, ½) is the center of symmetry for a strategy π and its antipodal strategy π−. Arrows point to better forecasts relative to a strategy π_0. They end on the lower envelope Γ of the error set { π } of all forecasts based on fixed information denoted by Molchan (2003) as the error diagram of optimal strategies. Dashed lines are contours of the loss function γ = max(n, τ), and point Q* determines the minimax strategy, n = τ = γ*. Dash-dotted lines are contours of the loss function γ = τ/(1 − n) that denotes probability gain. Note that all probability gain contours meet at point A, i.e. optimistic strategy. That is why short-term forecast/predictions may reach rather high probability gains, in particular, when an individual case-history is considered.

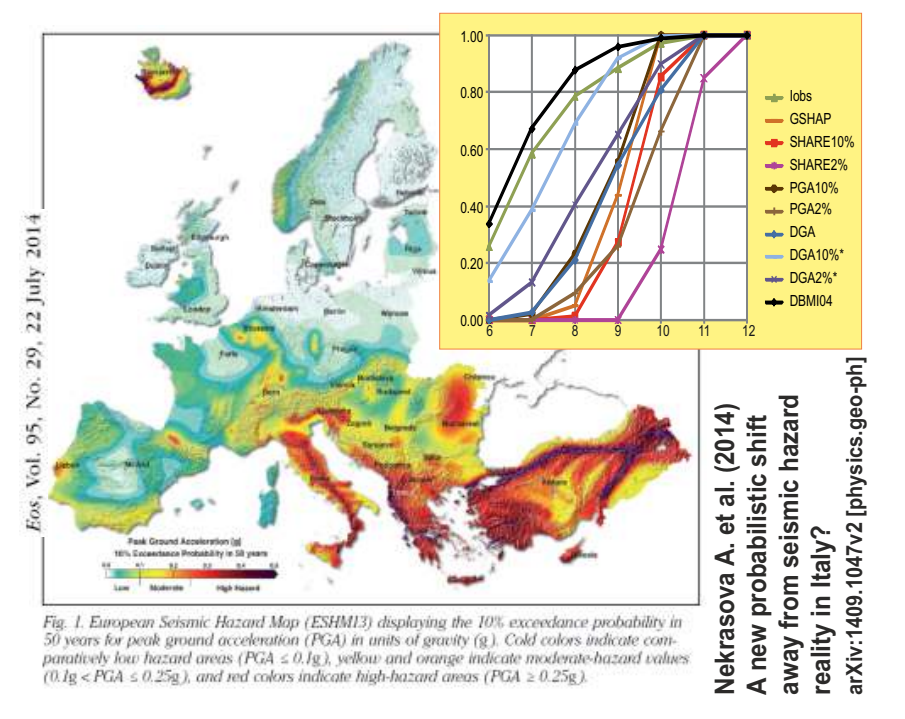
How earthquake prediction methods work?

> "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, 1997)

Probabilistic Seismic Hazard Analysis, PSHA



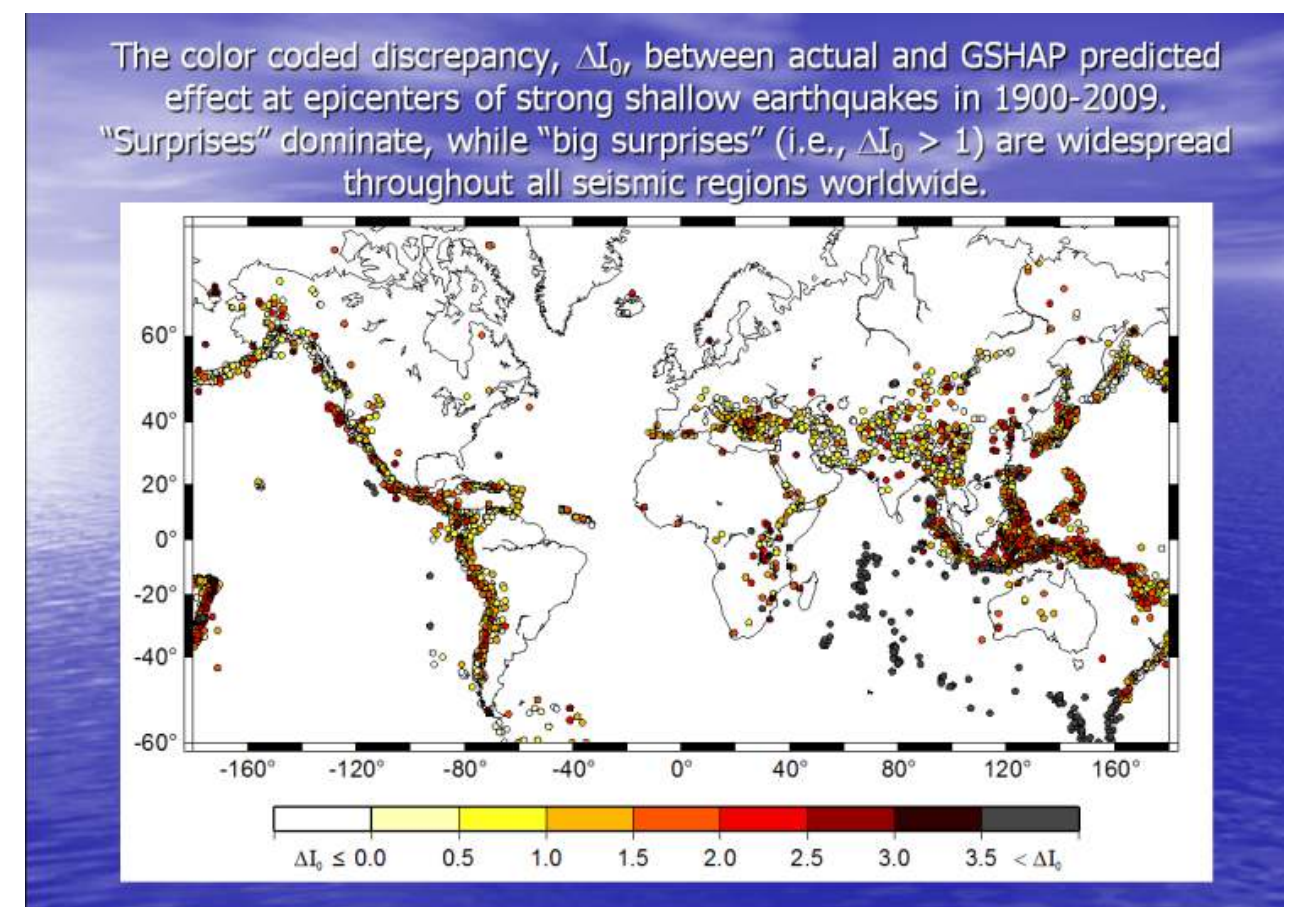


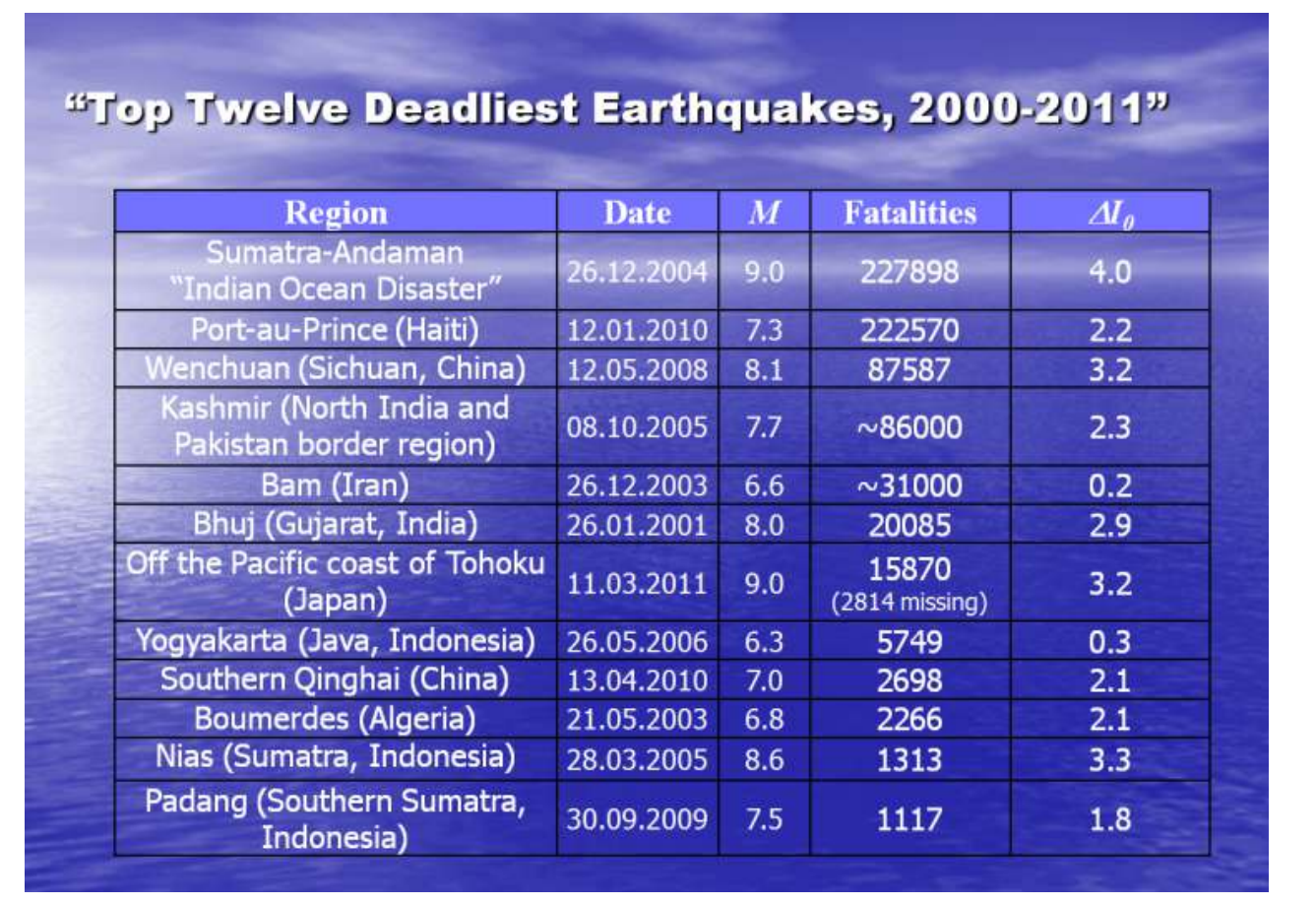


Nekrasova A. et al. (2014)
A new probabilistic shift away from seismic hazard reality in Italy?
arXiv:1409.1047v2 [physics.geo-ph]

For SHARE2% map the departure reaches up to 4 units of macroseismic intensity, too much to agree with a possibility of its practical applications.

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.



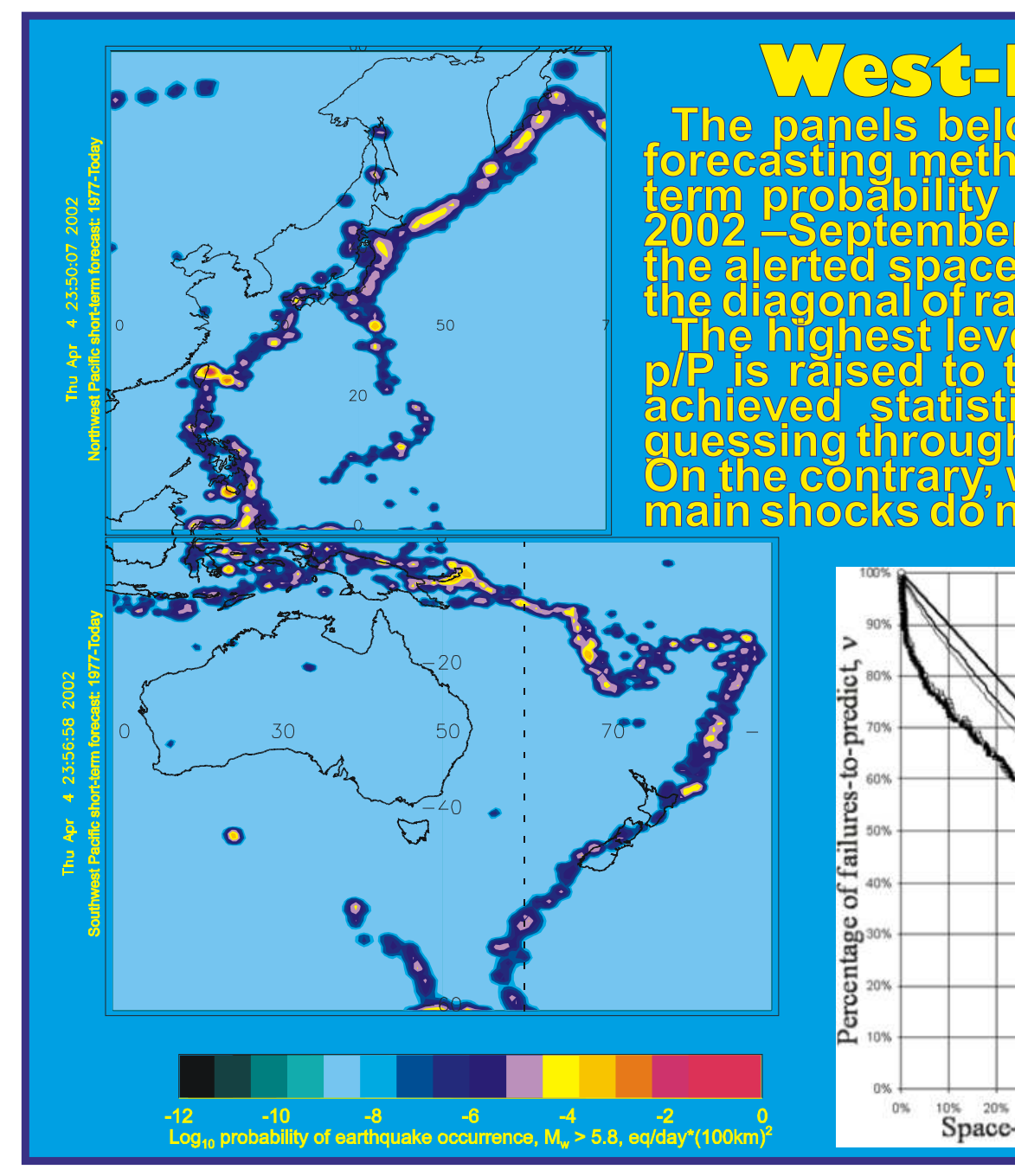


"Top Twelve Deadliest Earthquakes, 2000-2011"

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 Tohoku (Japan)	11.03.2011	9.0	15870 (2814 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

We urge therefore the necessary revision of widespread PSHA maps, resorting to physically sound deterministic methods [Italian Chamber of Deputies, 2011]. The maximal magnitude of an expected earthquake for seismically hazardous areas can be estimated with a statistically justifiable reliability [Kijko, 2012]. Deterministic scenarios of catastrophic earthquakes may provide comprehensive basis for decision-making, from land-use planning, adjusting building codes and regulations to the operational emergency management.

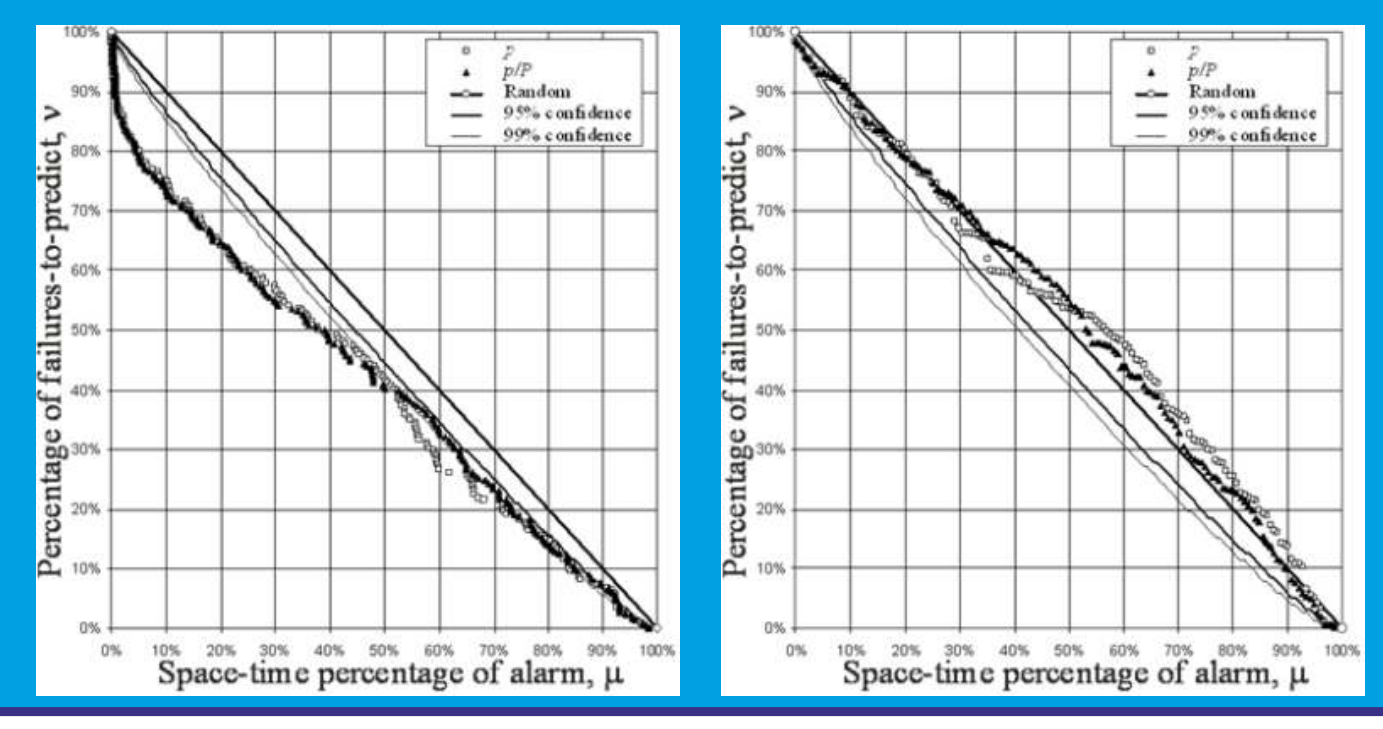
Civil engineers search for reliable alternatives to PSHA

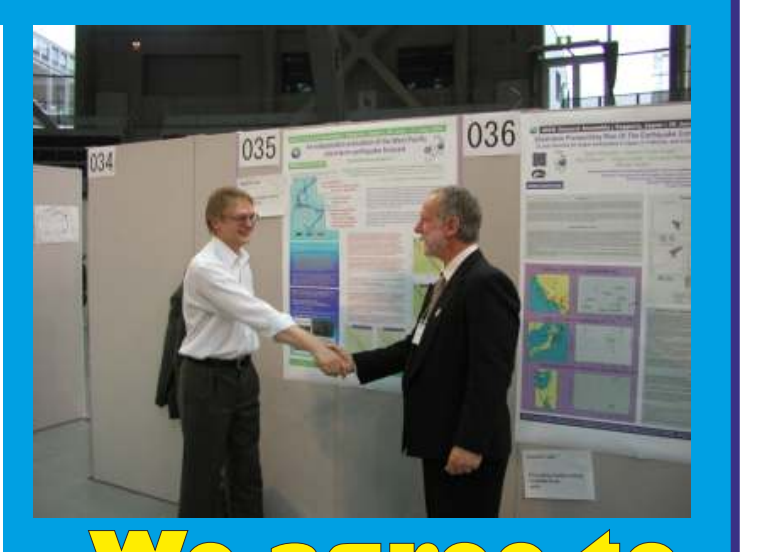


West-Pacific short-term forecasts

The panels below displays the empirical error curves for Jackson and Kagan (1999) forecasting methods based on short-term probability p and its ratio p/P relative to long-term probability P (for details see Kossobokov, 2006). In real-time testing period April 2002 –September 2004 the percentage of failures-to-predict ν versus the percentage of the alerted space–time volume μ, equivalent to (n, τ), fall outside 99%-confidence limit of the diagonal of random guessing.

The highest level of probability gain above 100 is achieved when the threshold for p or p/P is raised to the maximal value that yet permits predicting a single one event. The achieved statistics for 218 target earthquakes (left) are much better than random guessing through wide ranges of μ (and the corresponding threshold values of p and p/P). On the contrary, when aftershocks are excluded from set of targets, the prediction of 151 main shocks do not outscore at all random guessing (right).

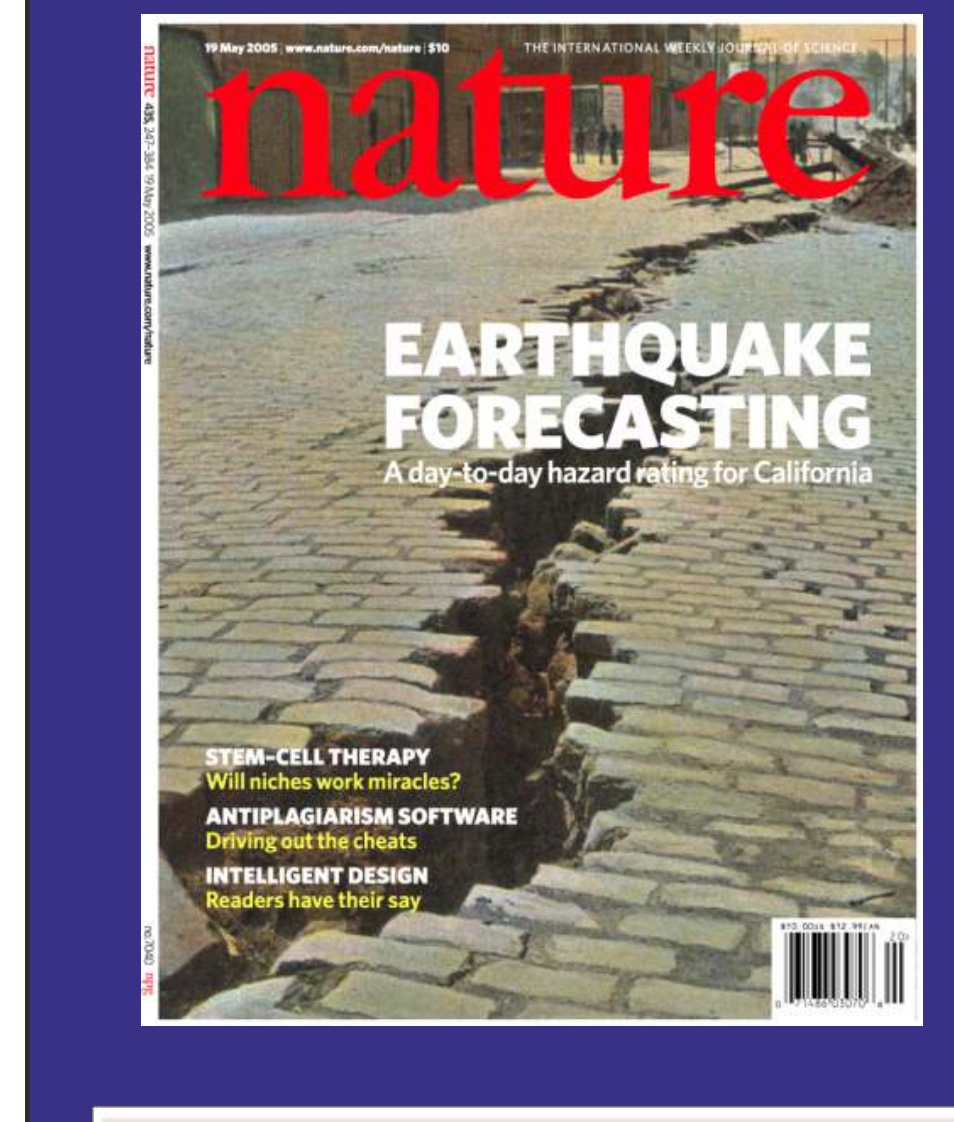




We agree to DISAGREE !

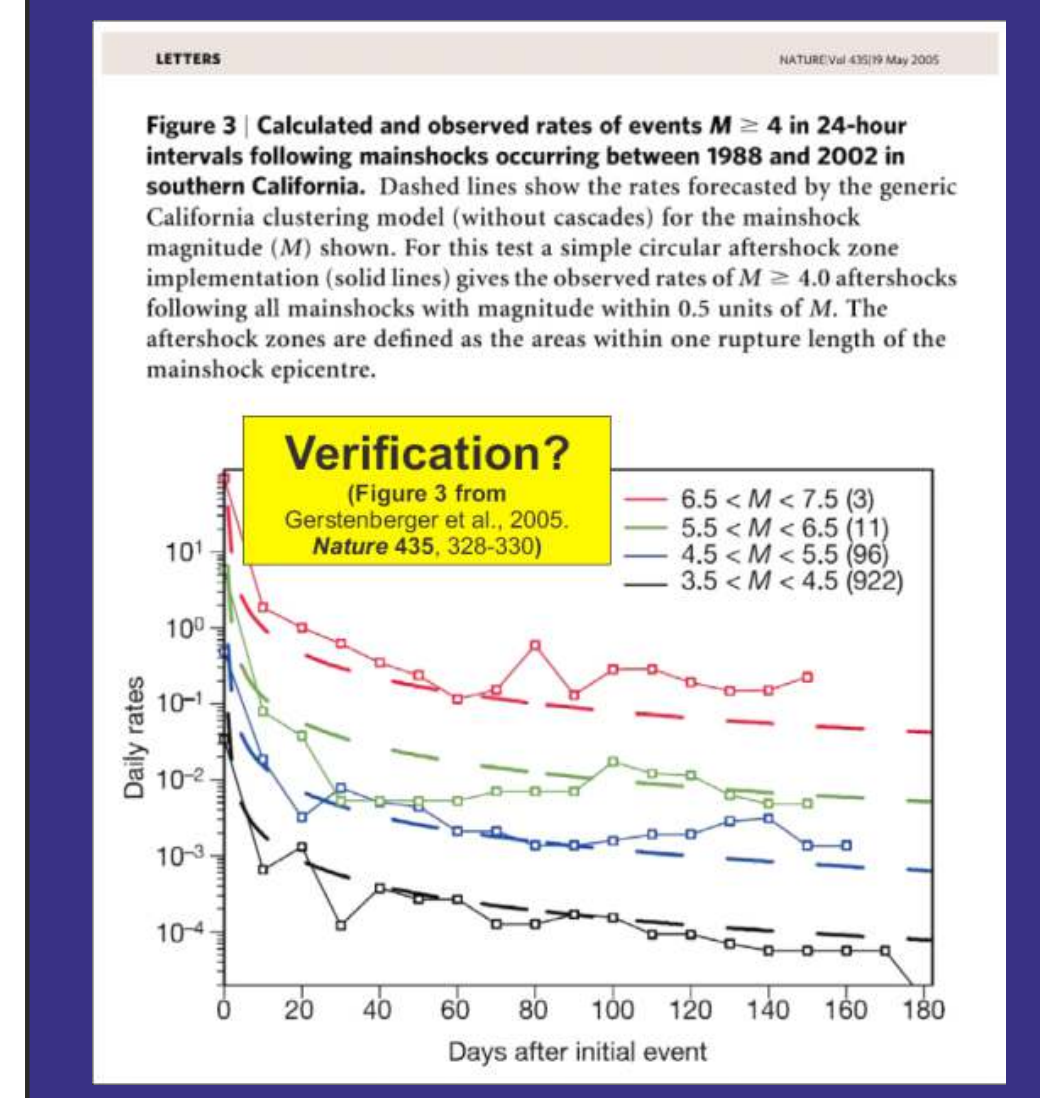
Jordan et al. (2014) mention as an example of Operational Earthquake Forecasting the short-term earthquake probability (STEP) model, which poor performance could have been anticipated before publication in Nature (Gerstenberger et al., 2005) and starting up the US Geological Survey site, showing daily ground-shaking probabilities in California. Kossobokov (2005; 2006) based on the 15 years of seismic record statistics from (Gerstenberger et al., 2005) presented a half-page proof that suggests rejecting with confidence above 97% "the generic California clustering model" used in calculation of forecasts of expected ground shaking for tomorrow. The poor performance of STEP was eventually confirmed (Kossobokov, 2008): in 1060 days of the real-time forecasting the five earthquakes of Modified Mercalli intensity VI in California have occurred in the areas of the web-site's lowest-risk (about 1/10000 or less), while the extent of the observed areas of intensity VI for these events (about 100 cells in total) is by far less than the expected number of cells experiencing VI or greater shaking (about 850 cells). "A site, showing daily ground-shaking probabilities in California, … was subsequently removed because of coding problems" (Cartlidge, 2014).

Real-time forecasts of tomorrow's earthquakes in California.



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* ≥ 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.

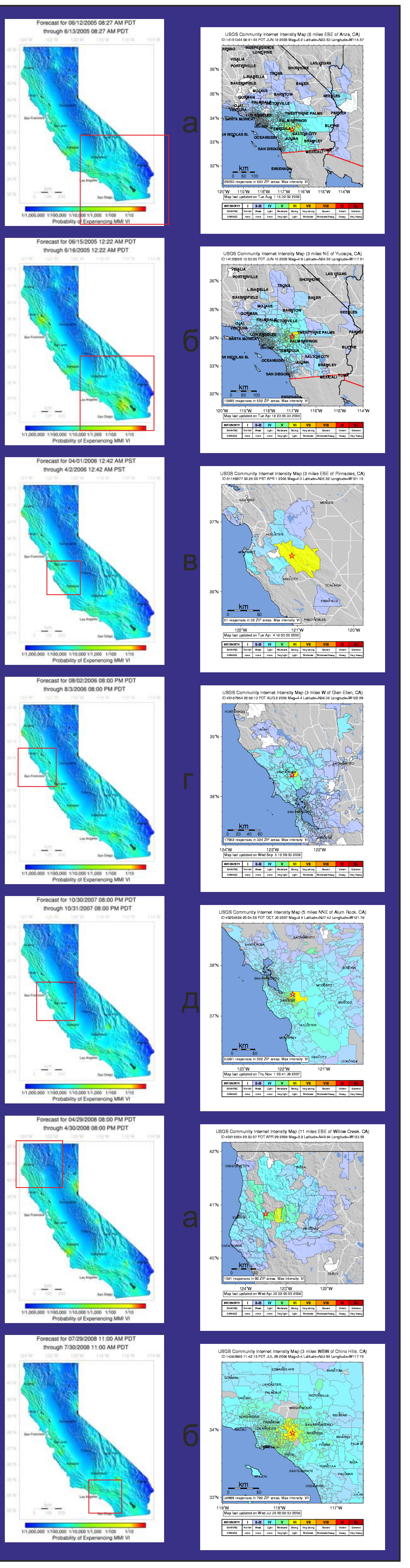
Verification?
(Figure 3 from Gerstenberger et al., 2005. *Nature* **435**, 328-330)

"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)."

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. ■

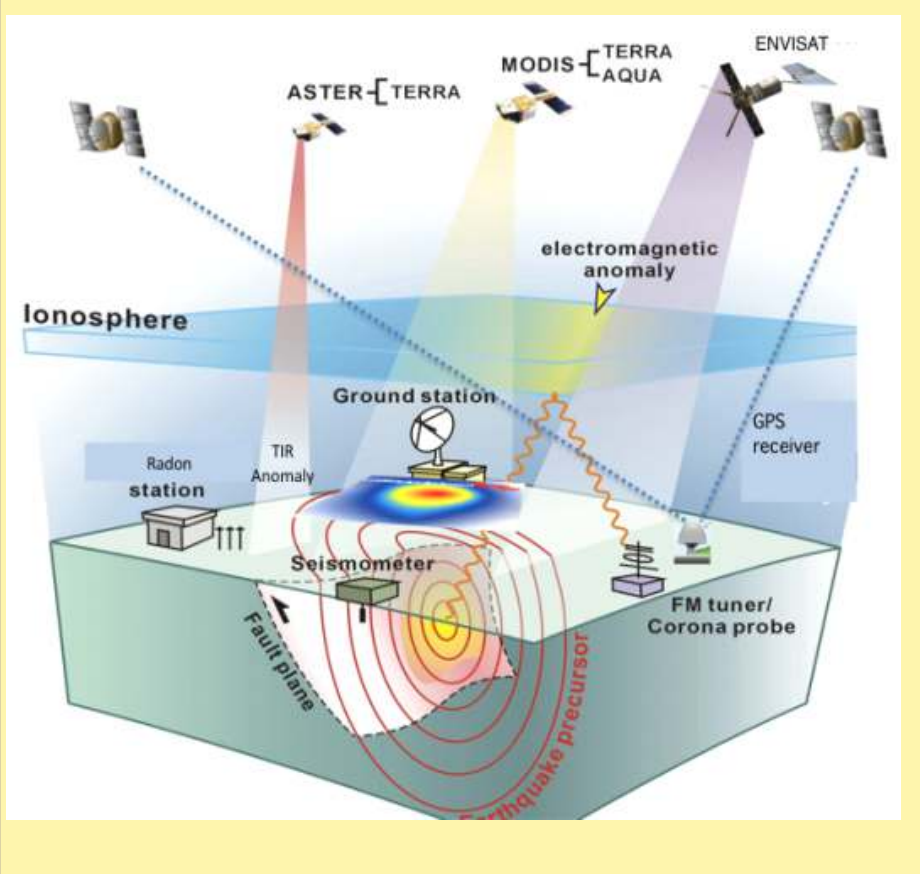
DISCONTINUED

DUE TO CODING PROBLEMS.



Terra Seismic Plc (Terra) provides daily, 30-day earthquakes alerts for 150 countries. The Terra team uses innovative satellite-based technologies and unites leading international geoscientists with financial experts in developing novel solutions for insurance and reinsurance industries, financial markets players, governments, early warning systems (EWS), Large Catastrophe Modelers, and Disaster Risk and Responders (DRR.

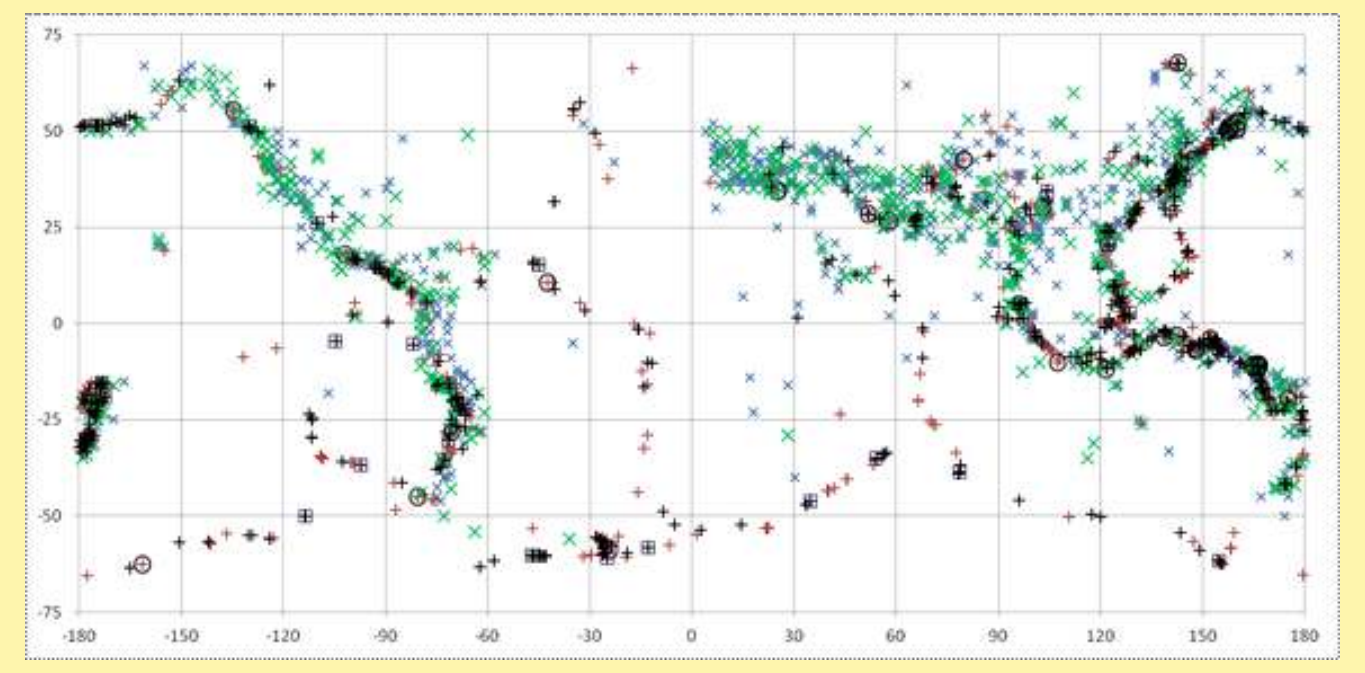
How can earthquakes be forecasted 20-30 days before they occur?



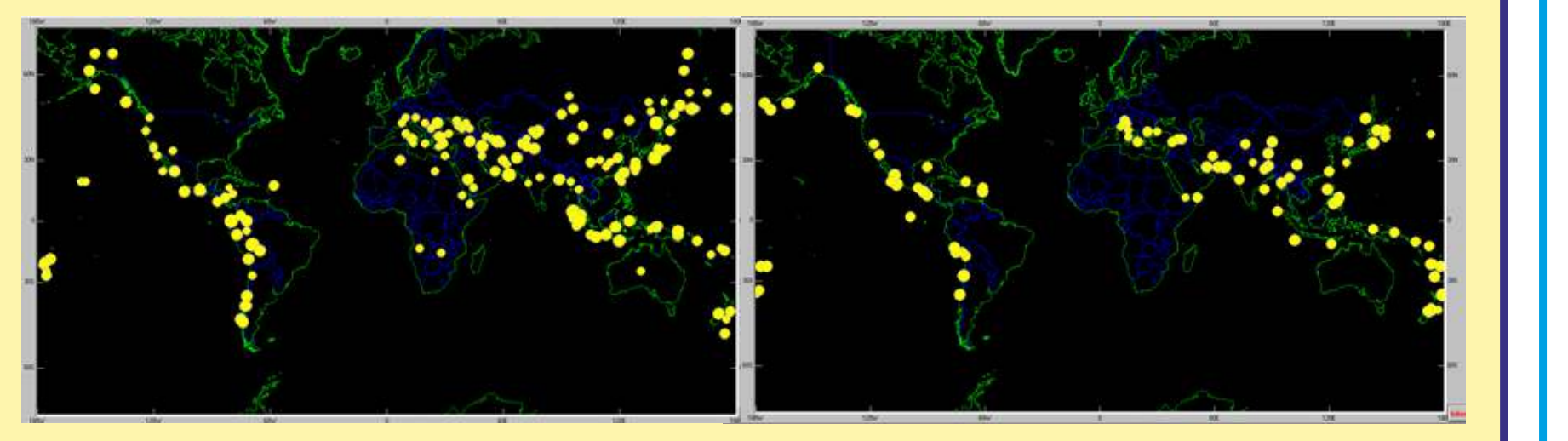
"This consolidated model can identify the region of future earthquakes up to 30 days before the event.

Up to now, this has been impossible, and we want to share this amazing technology with you, so we can save lives and educate the world about these events."

The Terra Seismic forecasts in 2013/01/01-2013/11/11



The TS forecast locations and earthquake epicenters, 2013/01/01-2013/11/11. Forecasts issued in 2013/01/01-2013/07/01 are marked with blue while those in 2013/06/30-2013/11/11 – with green crosses; earthquakes of magnitude 5 or more in 2013/01/01-2013/06/30 are marked with red pluses while those in 2013/06/30-2013/11/11 – with black ones, those of magnitude 6.0 or above are outlined with a square or a circle if happened in 2013/01/01-2013/06/30 or 2013/07/1-2013/11/11, respectively.



The TS forecast locations on 2013/02/01 (left) and on 2013/11/11 (right). Each forecast is marked with a yellow circle which size corresponds to the magnitude of event.

Evaluation of the effectiveness the TS predictions

Period	"Successes"	"Failures"	Total	M easure *p*, %	Confidence, %
01.01-06.30 2013	12 (19.05%)	51 (80.95%)	63	29.00	0.03
07.01-11.20 2013	8 (16.00%)	42 (84.00%)	50	24.85	0.05
01.01-11.20 2013	20 (17.70%)	93 (82.30%)	113	27.34	0.01

There are 8 out of 20 "successes" with underestimation of magnitude greater than 1, while in one case the magnitude was overestimated by 0.9 (which case should, perhaps, be excluded from "success" score).

The number of successes increases from 20 to 28, if we accept the spatial uncertainty of a forecast in respect to the expected earthquake magnitude. This is 24.78% of the total trial earthquakes that is less than 27.34% of the expected performance of random guessing. Therefore, this change will raise confidence to just about 24%, i.e. far below any common levels (e.g. 95%, 97%, 99% etc.).

Thus, it follows that the TS predictions in 2013 by D. Ouzounov are hardly delivering any info on an incipient strong earthquake.

MANY THANKS TO THE AUTHORS OF SEISMIC HAZARD ASSESSMENTS WHO PROVIDED CLEAR RECORD ON THEIR FORCASTS/PREDICTIONS !