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New Approaches to Seismic Hazard Assessment

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New Approaches to Seismic Hazard Assessment

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18. Fatal flaws in attempts to reduce seismic risk

(**from Roger Bilham "The seismic future of cities".** Bull Earthquake Eng - DOI 10.1007/s10518-009-9147-0
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The following is a list of potentially fatal flaws in our present day application of earthquake risk reduction. It is by no means exhaustive and not all of the problems identified are applicable to all countries. Some are corrupt practices, and others are incorrect assumptions. All can be ascribed to ignorance in one form or another. The first four are intrinsic to the methodology of earthquake risk assessment. The remaining dozen items listed are issues that are rarely considered in risk estimation, but in the developing nations are responsible for current weaknesses in the implementation of safe housing:

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False Assumption #1. Seismic hazard maps or maps of seismic risk indicate the probability of future shaking intensity.

Seismic hazard maps are maps of the past! They represent an image of future shaking only where **two further assumptions are applicable—that the rate of seismic productivity does not change with time, or that the history they represent is sufficiently long to reveal all possible earthquakes.** This last assumption is equivalent to stating that the instrumental record, the historical record, and the paleoseismic record, sample the seismic cycle and its fluctuations in a region. These conditions are met with only in a few areas on earth.

False Assumption #2. ***The most recent seismic hazard map is the most reliable available.***

While a revised map is often driven by a well-intentioned need to revise estimates of seismic risk, it may in fact represent a map of the least-likely locations to be next visited by a damaging earthquake. ...

False Assumption #3. ***If sufficient funds and people are focussed on a local seismic risk problem, a reliable data base of historical data can be compiled to calculate probabilistic forecasts of future seismicity.***

False Assumption #4. ***A global view of earthquake risk will improve our understanding of local seismic risk.***

The assumption may be true in an actuarial sense, but breaks down where the local tectonic setting may differ from a recognisable global norm. ...

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- *False Assumption #5. Elected politicians are knowledgeable of the earthquake histories of their countries.*
- *False Assumption #6. Politicians will act responsibly when provided with estimates of seismic hazard.*
- *False Assumption #7. Tenders and sealed bids to avoid corrupt selection practices, guarantee safe construction.*
- *False Assumption #8. Building codes are universally enforced in nations where they have been adopted.*
- *…*

Learning is needed to fight "ignorance in one form or another".

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

Keiiti Aki (1930-2005)

Seismic activity is self similar:

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

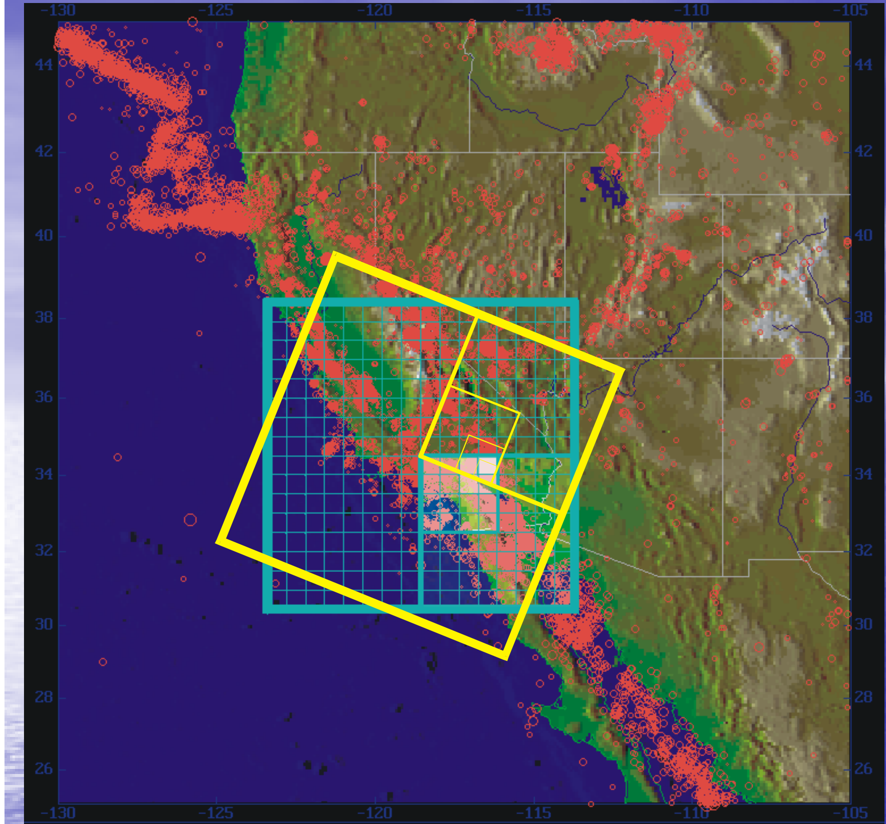
Okubo, P.G., K. Aki, 1987. Fractal geometry in the San Andreas Fault system. *J. Geophys. Res.*, **92** (B1), 345-356;
Садовский М.А., Болховитинов Л.Г., Писаренко В.Ф., 1982. О свойстве дискретности горных пород. *Изв. АН СССР. Физика Земли*, № 12, 3-18;
Садовский, М.А., Т.В. Голубева, В.Ф. Писаренко,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

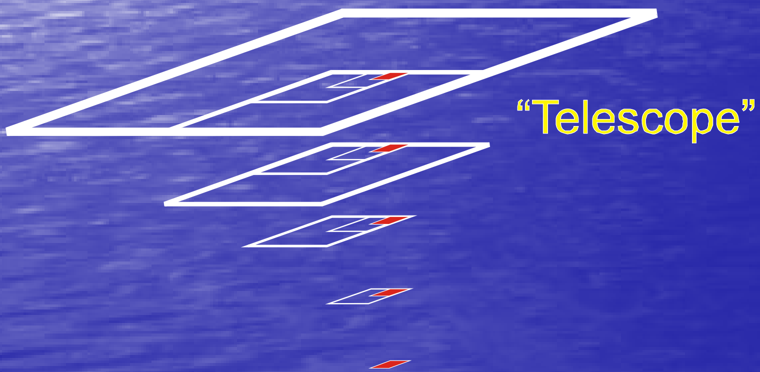
$$\log_{10}N = A + B\cdot(5 - M) + C\cdot\log_{10}L$$

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 scheme for box-counting

The counts in a set of cascading squares, **“telescope”**, estimate the natural scaling of the spatial distribution of earthquake epicenters and provide evidence for rewriting the G-R recurrence law.



The box-counting algorithm
(*Kossobokov and Mazhkenov, 1988*)

For each out of m magnitude ranges and for each out of h levels of hierarchy the following numbers $N_{j,i}$ are found:

$$N_{j,i} = \Sigma\, n_i\, (Q_i)^2 / N_j\ ,$$

where i = 0,1….h-1, j = 1,2….m, $n_j(Q_i)$ is the number of events from a magnitude range M_j in an area Q_i of linear size L_i; N_j is the total number of events from a magnitude range M_j.

The A, B, C's are derived by the least-squares method from the system

$$\mathbf{log_{10}} N_{j,i} = A + B\cdot(5 - M_j) + C\mathbf{log_{10}} L_i.$$

An interpretation of the box-counting

Number N_{ji} can be considered as the empirical mean recurrence rate of events in the magnitude range M_j, calculated over their locus in an area at the i-th level of spatial hierarchy.

Specifically, if we denote a "telescope" a set of h+1 embedded squares $W = \{w_0, w_1, \ldots , w_h\}$, so that each w_i belongs to the I-th level of hierarchy. Note that each "telescope" grows uniquely from the lowest level. Assume that the M_j epicenter set is defined by a sample catalog of earthquakes $X_j = \{x_1, \ldots , x_{Nj}\}$. Each earthquake x_k defines the "telescope" $W(x_k)$ that grows from $w_h(x_k)$, to which x_k belongs. Consider the set of "telescopes" $\{W(x_k)\}$that corresponds to the catalog X_j. Denote $n_j(w_i)$ as the number of events from X_j that fall within w_i.

Then, the mean number of events in an area of i-th level of hierarchy over X_j is $N_{ji} = \Sigma_{\{k=1,\ldots,Nj\}} n_j(w_i(x_k)) / N_j$.

Substituting summation over X_j by summation over the areas $w_i(x_k)$ from the i-th level, we obtain the formula of the USLE.

The first results *(Kossobokov and Mazhkenov, 1988)*

The method was tested successfully on artificial catalogs with prefixed A, B and C and applied in a dozen of selected seismic regions from the two hemispheres of the Earth to a certain intersection of faults.

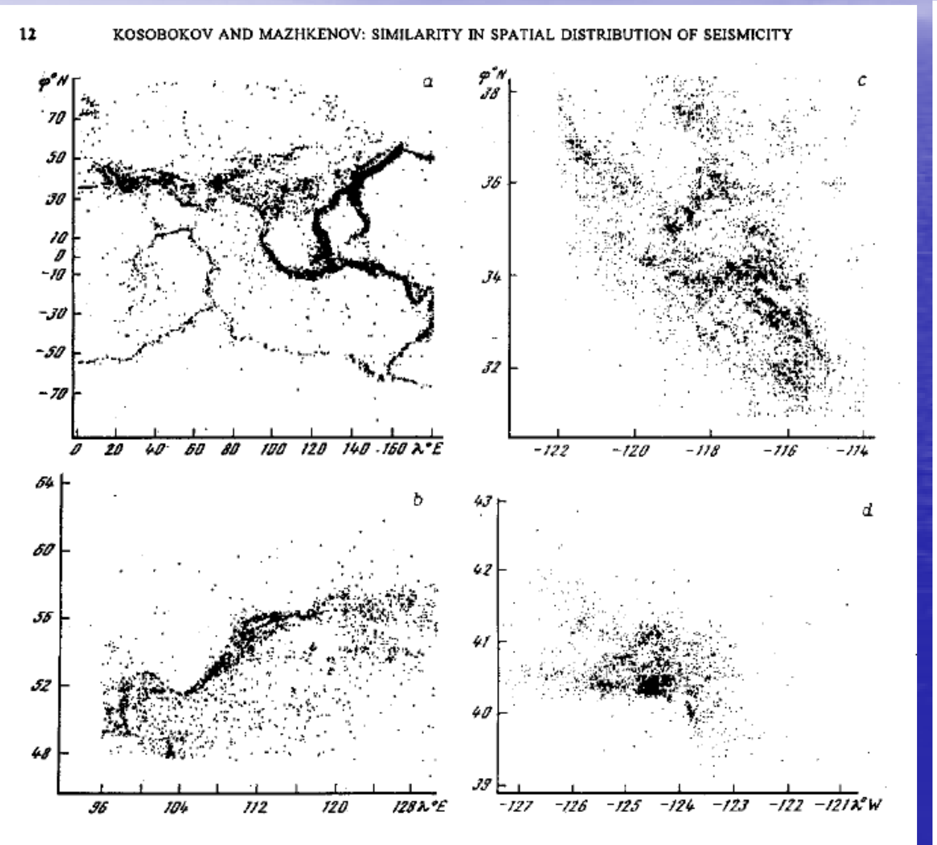


Fig. 2. Examples of spatial distribution of epicenters from catalogs of mainshocks. (a) Eastern Hemisphere. (b) Lake Baikal area. (c) Southern California. (d) The Cape Mendocino vicinity.

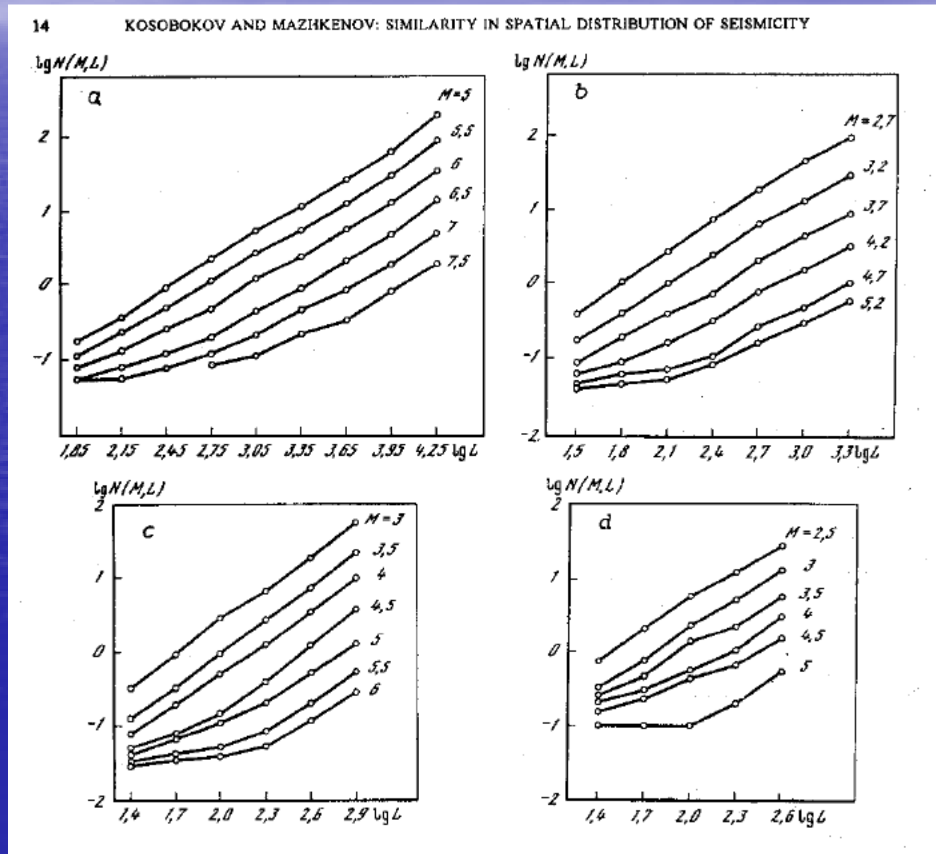


Fig. 3. Examples of log $N(M, L)$ graphs. (a) Eastern Hemisphere. (b) Lake Baikal area. (c) Southern California. (d) The Cape Mendocino vicinity.

The Unified Scaling Law for Earthquakes

We revisited the problem after Per Back et al. suggested the Unified Scaling Law for Earthquakes in a different formulation (with substitutes of 1/N = T and M = $\mathbf{Log_{10}}$ S),

"To understand the Unified Law for Earthquakes, it is essential to see what the value of x represents. The quantity $L^{df} \cdot S^{-b}$ in the scaling function represents the average number of earthquakes per unit time, with seismic moment greater than S occurring in the area size L × L. Therefore, x is a measure of the number of earthquakes happening within a time interval T. The Unified Law states that the distribution of waiting times between earthquakes depends only on this value."

Bak, P., K. Christensen, L. Danon, and T. Scanlon, 2002.
Unified Scaling Law for Earthquakes.
Phys. Rev. Lett. 88: 178501-178504

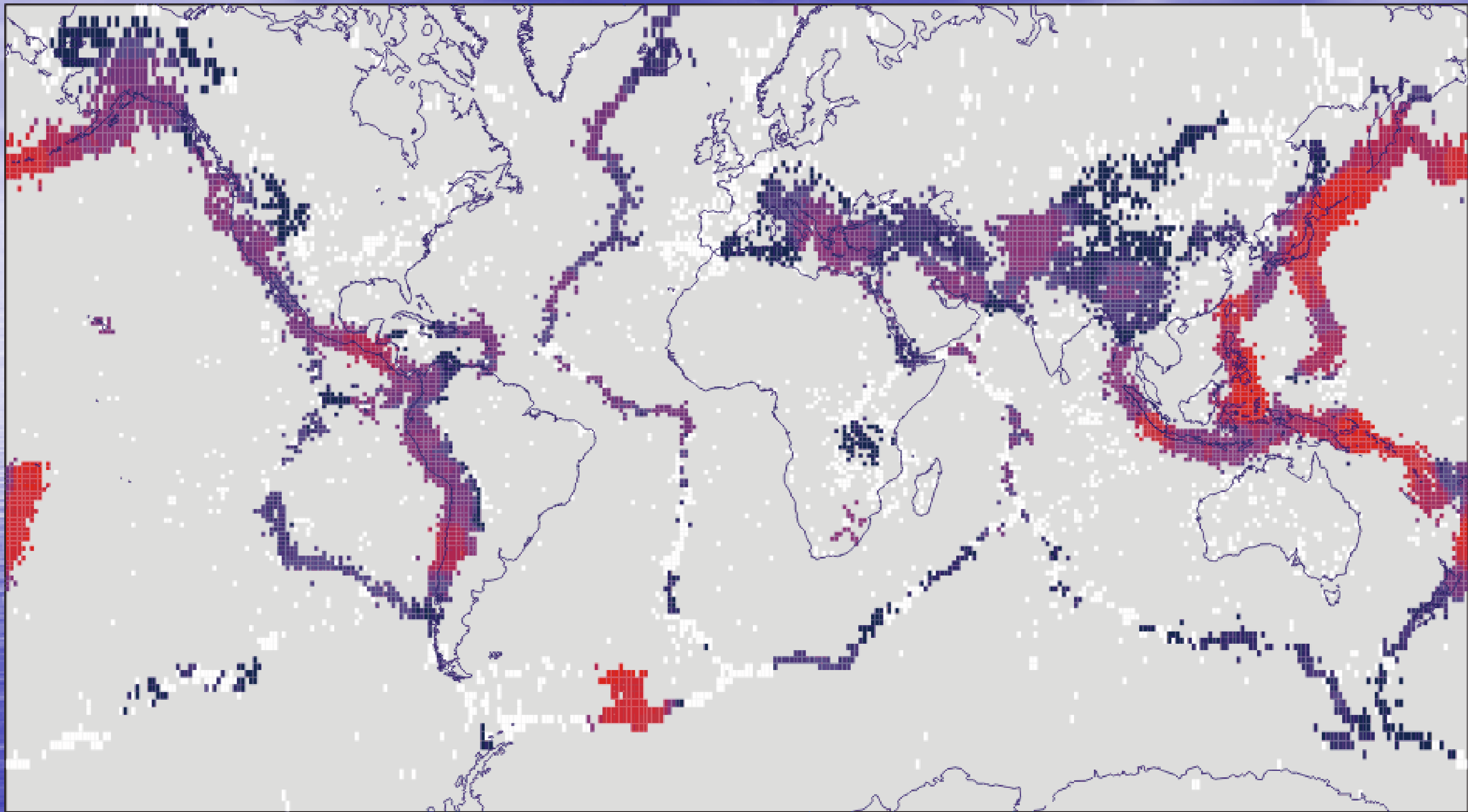
Revisiting the ABC problem on a global scale: **The Global Seismic Hazard maps display the A, B, and C's for earthquakes**

The data from the US GS/NEIC hypocenter data base permitted us to investigate systematically regions from a wide range of seismic activity, A (that differ by a factor up to 30 or more).
We found, for earthquakes with hypocenters above 100 km –

- the balance between magnitude ranges, B, varies mainly from 0.6 to 1.1 with a sharp maximum of density at 0.9, while

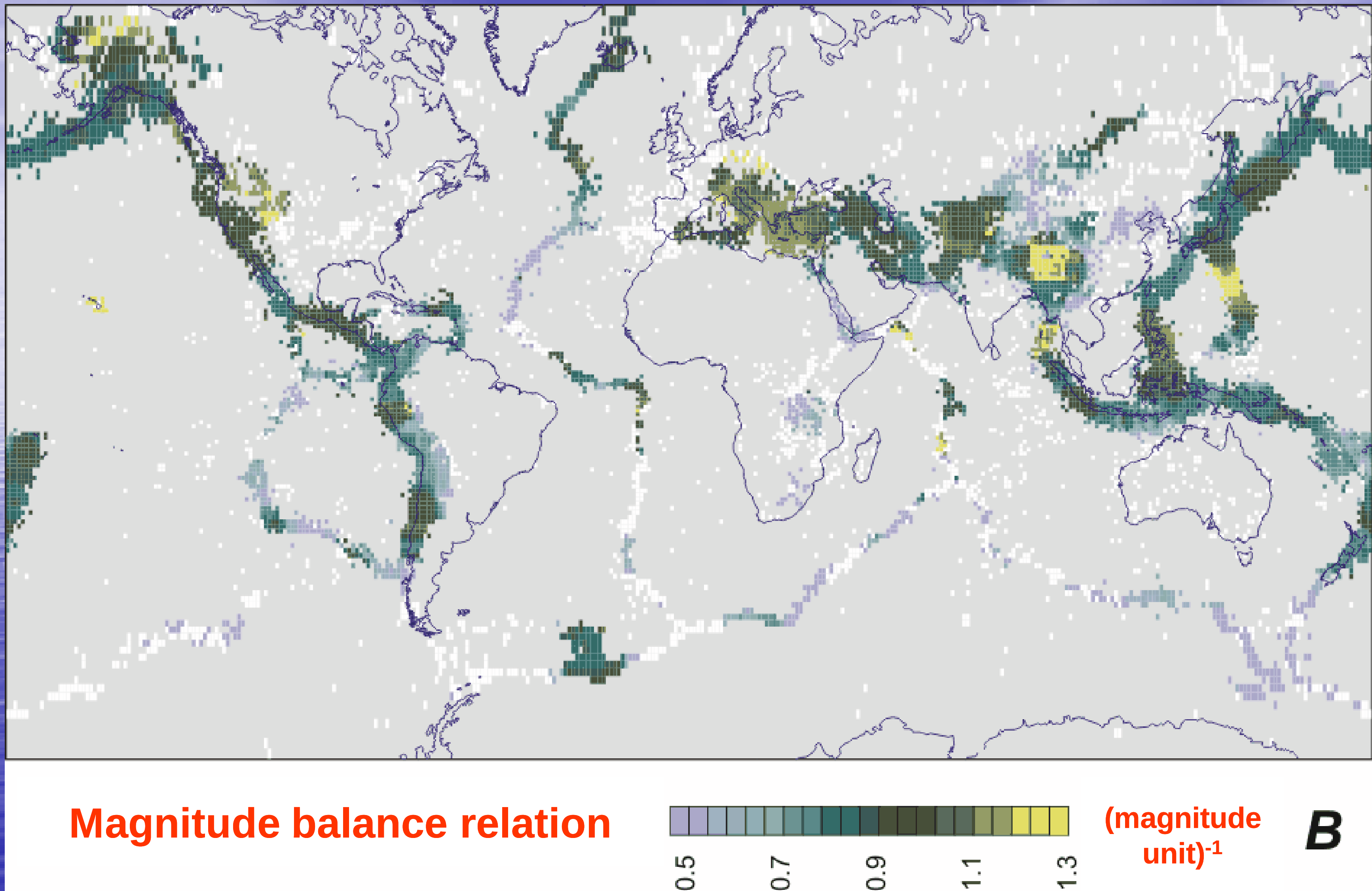
- the fractal dimension, C, changes from under 1 to 1.6 with a maximal density within 1.2-1.3.

The Global Seismic Hazard map: Coefficient A

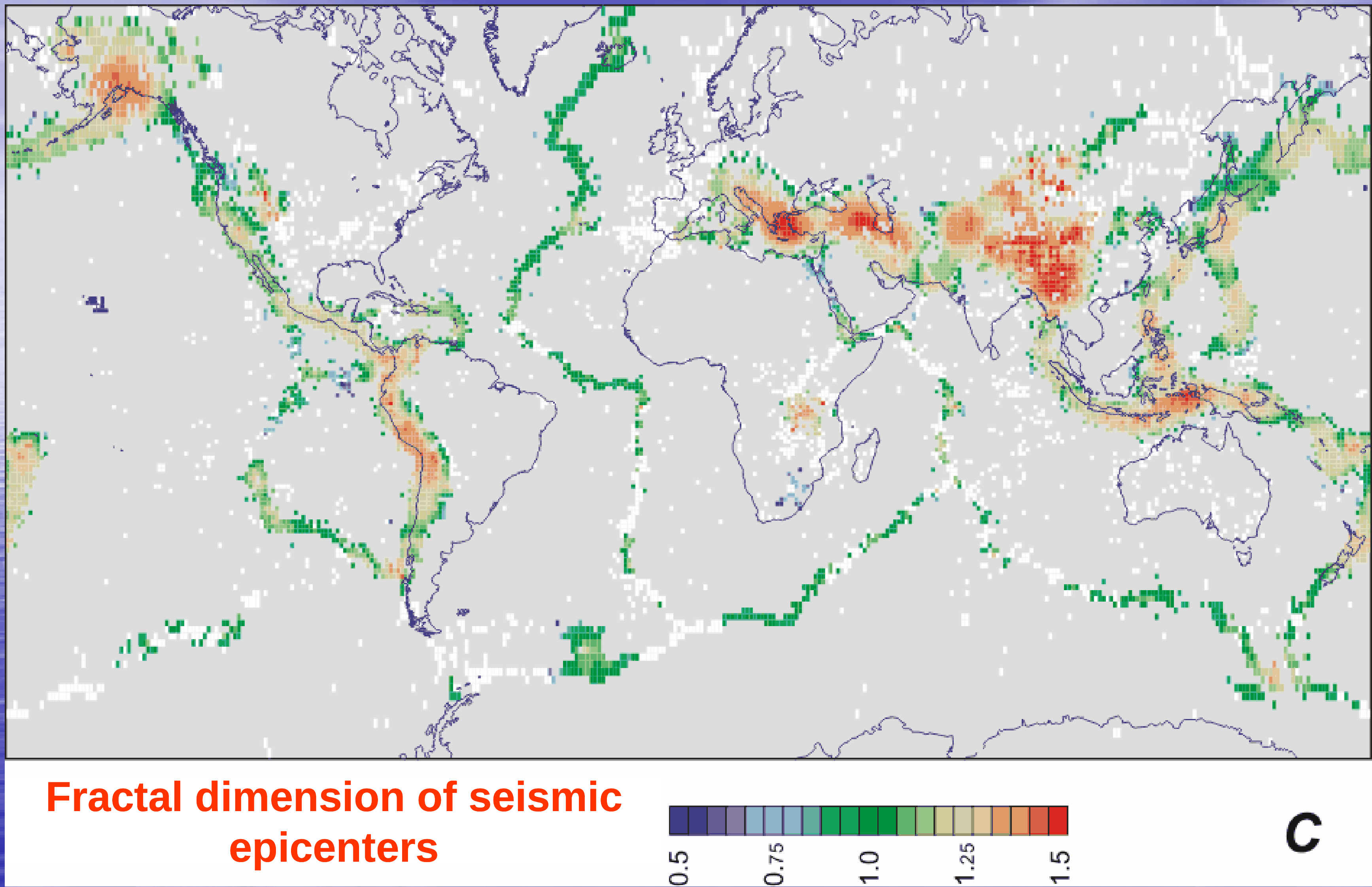


Logarithm of recurrence rate -1.2 -0.7 -0.2 0.3 0.8 year^{-1} ***A***

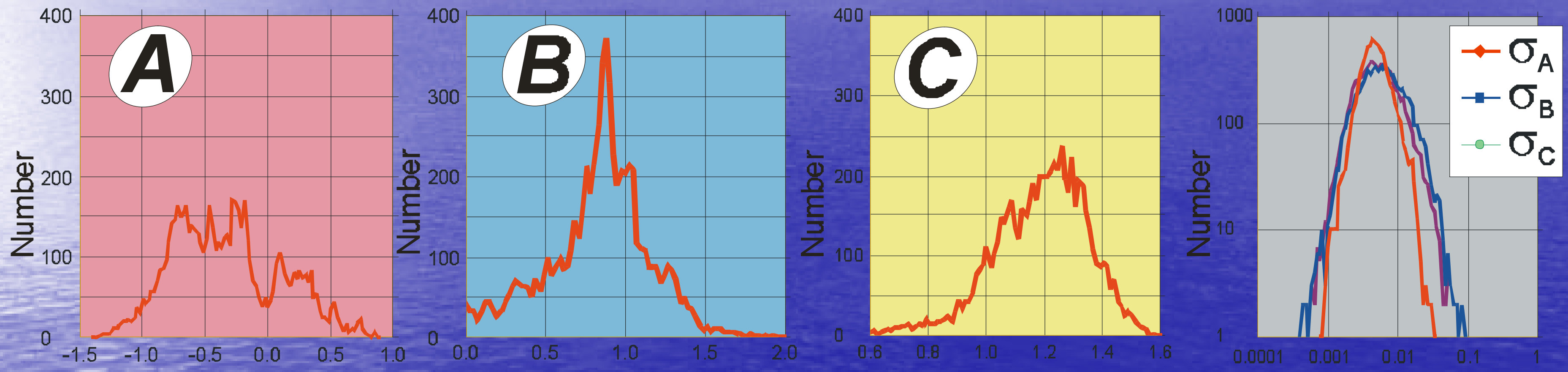
The Global Seismic Hazard map: Coefficient B



The Global Seismic Hazard map: Coefficient C

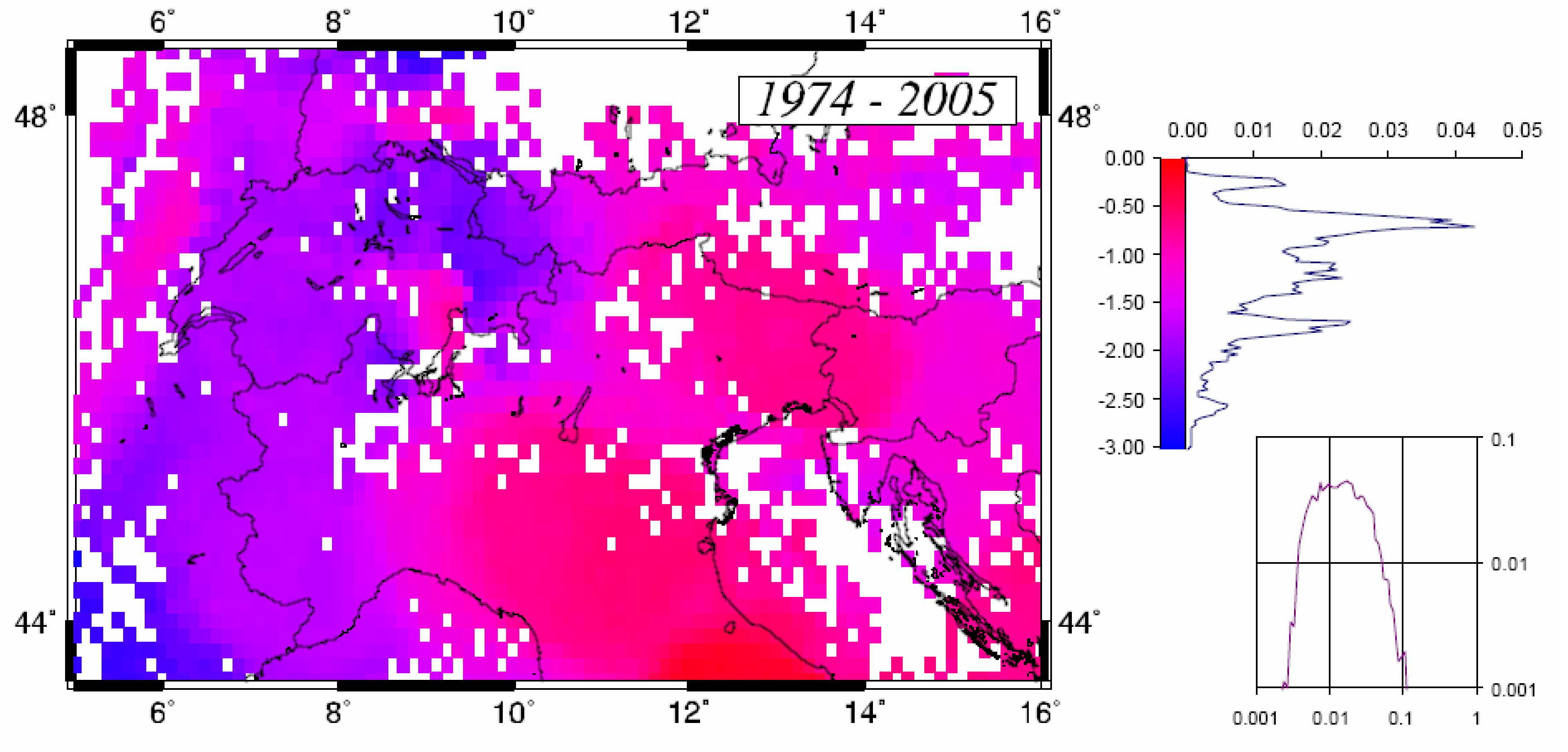


Histograms of A, B, C and σ's

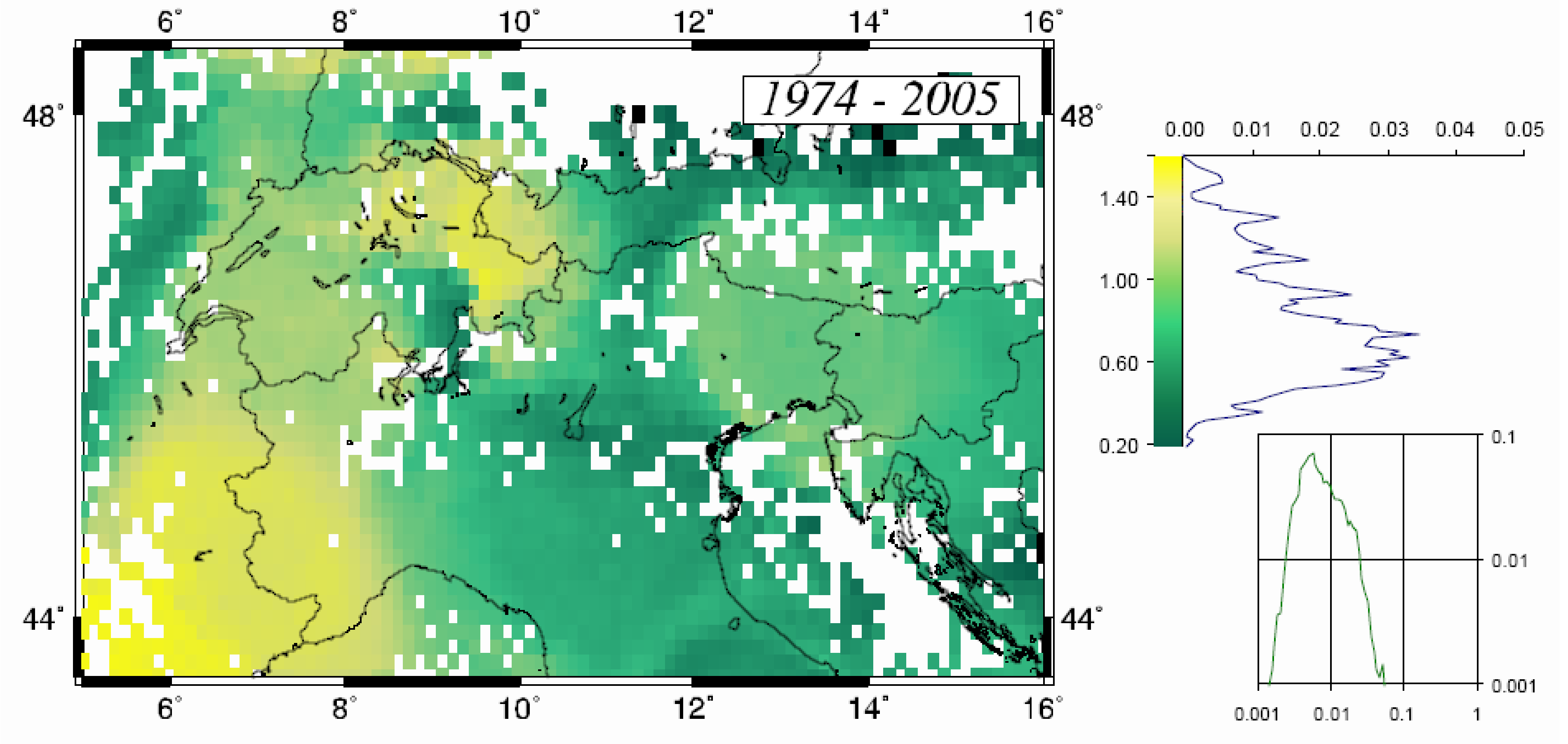


Note: The histogram of the coefficients' value errors, σ's, given in logarithmic scales. It suggests high degree of overall agreement with the assumption of self-similarity used in computations.

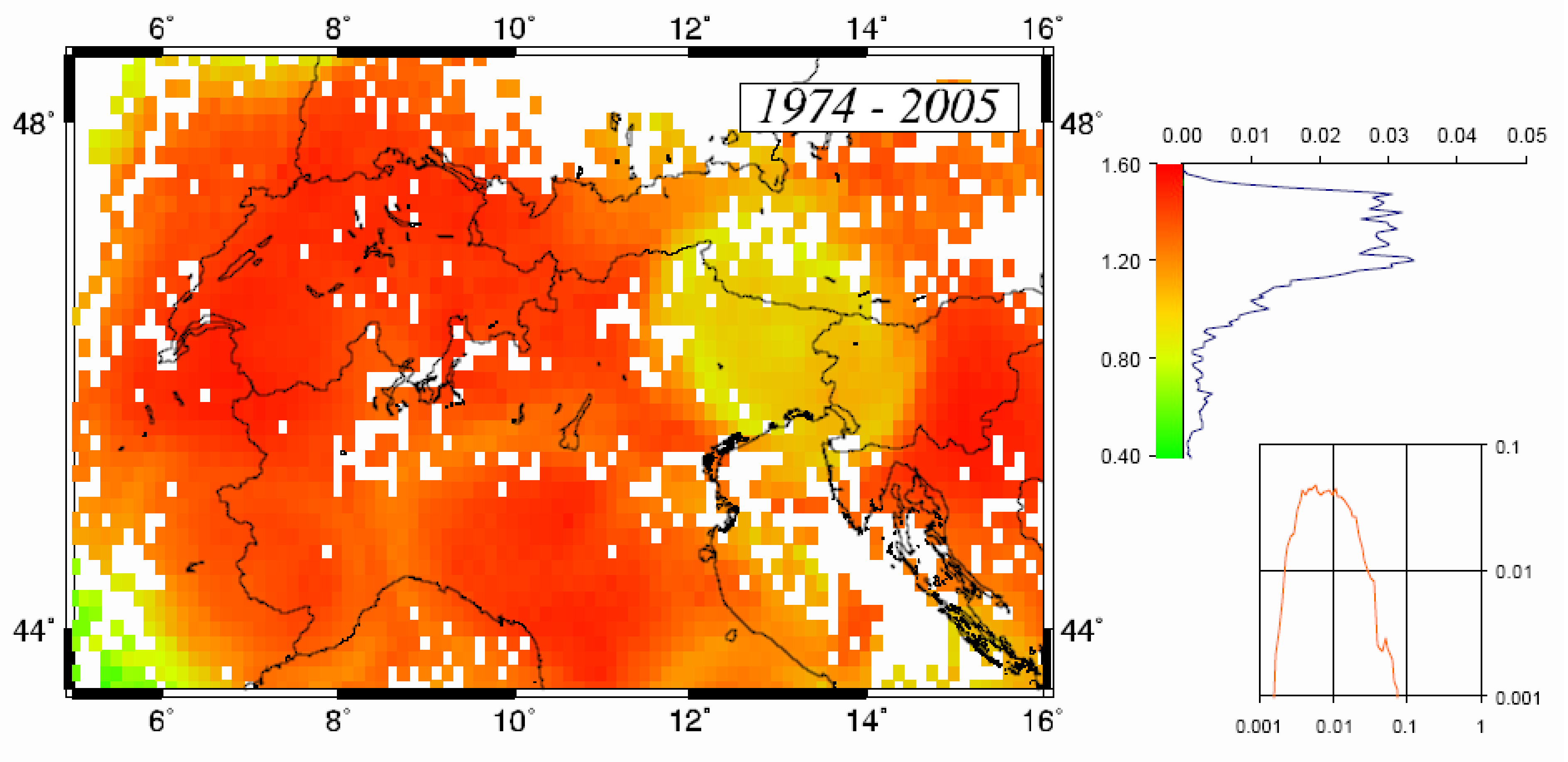
The Regional Seismic Hazard Map: Northern Italy

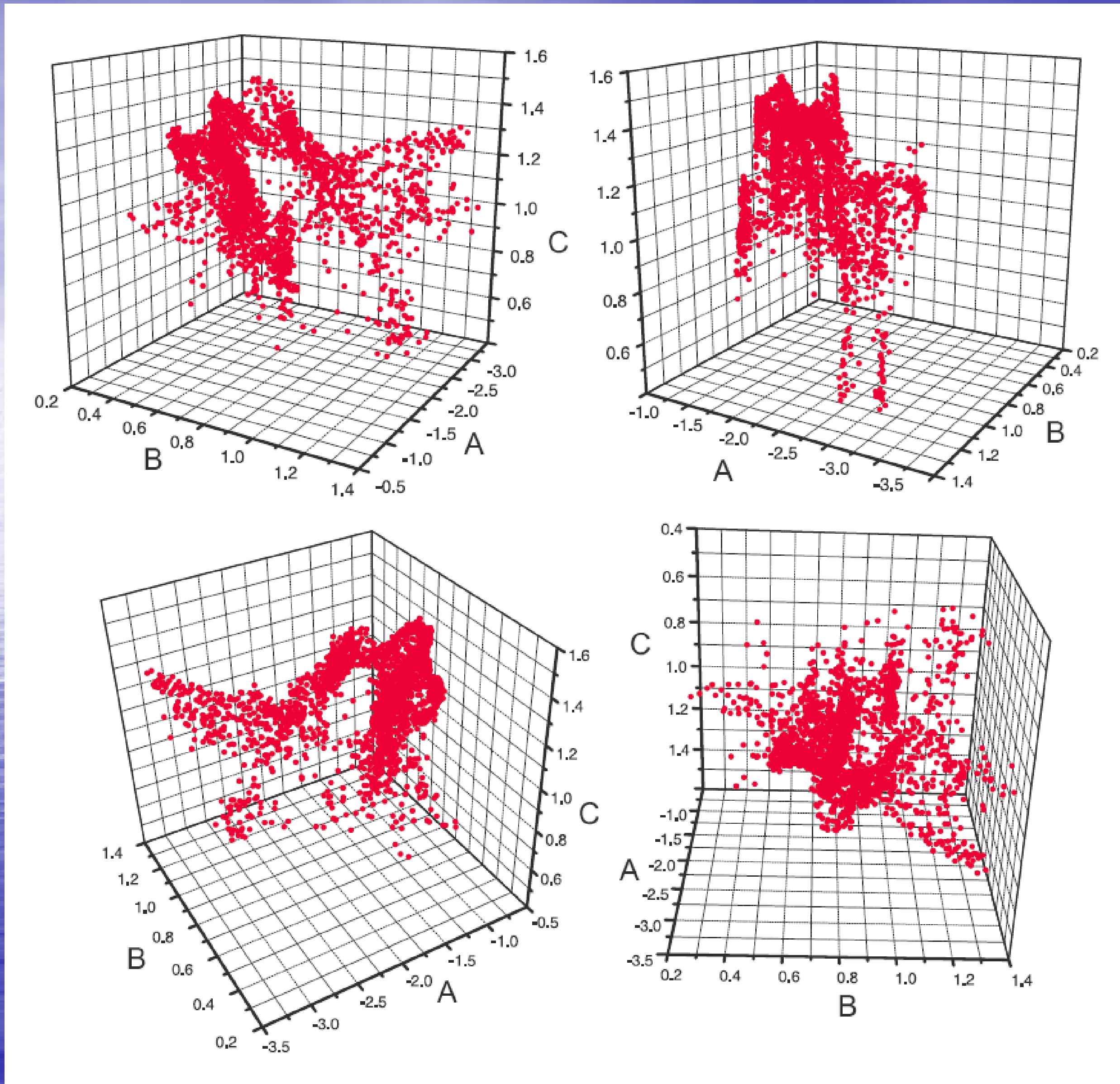


The Regional Seismic Hazard Map: Northern Italy



The Regional Seismic Hazard Map: Northern Italy





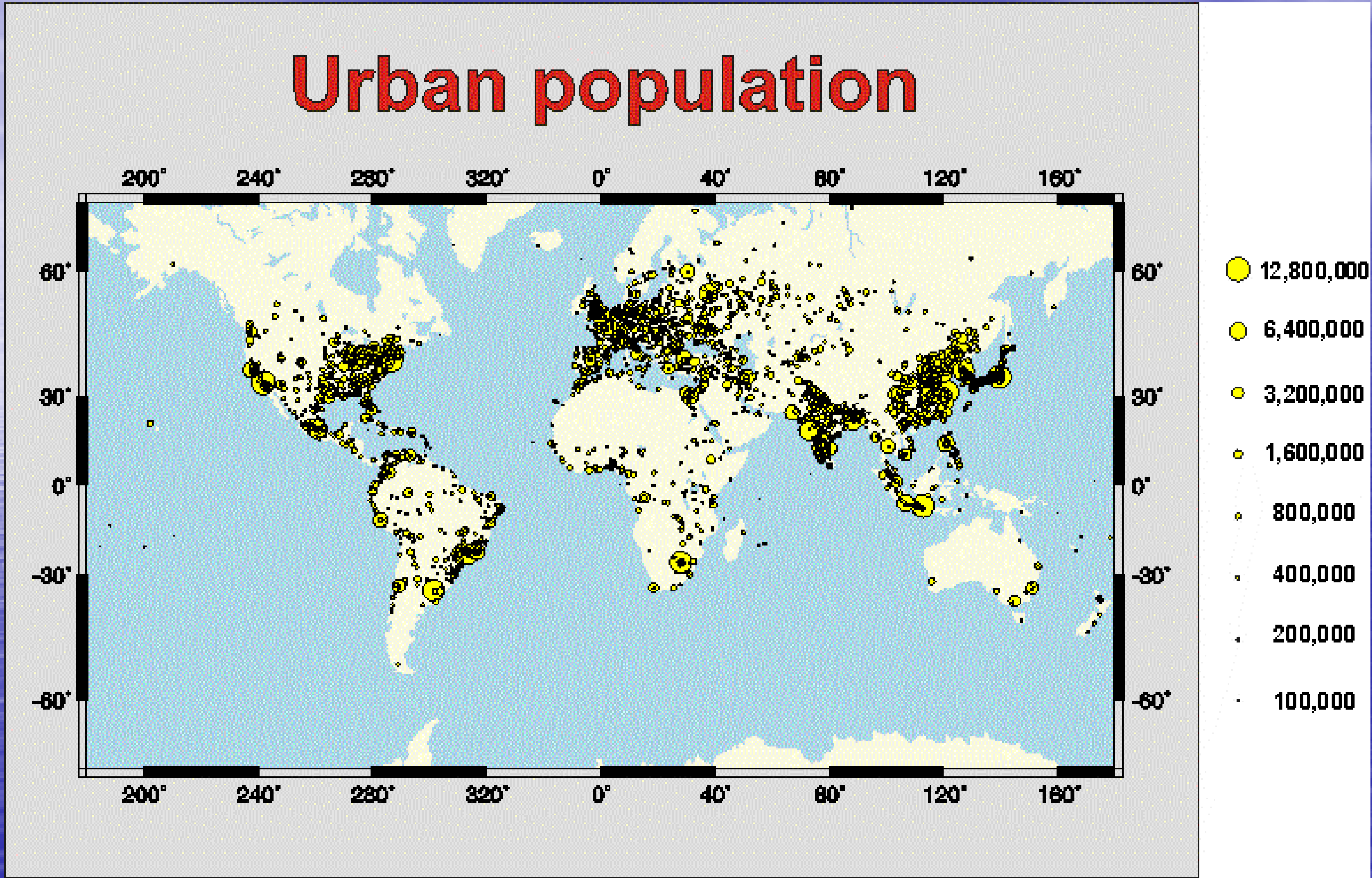
Sample 3-D views of the 2352 combinations of *A*, *B*, *C* coefficients in Italy and surroundings, 1870-2005.

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.

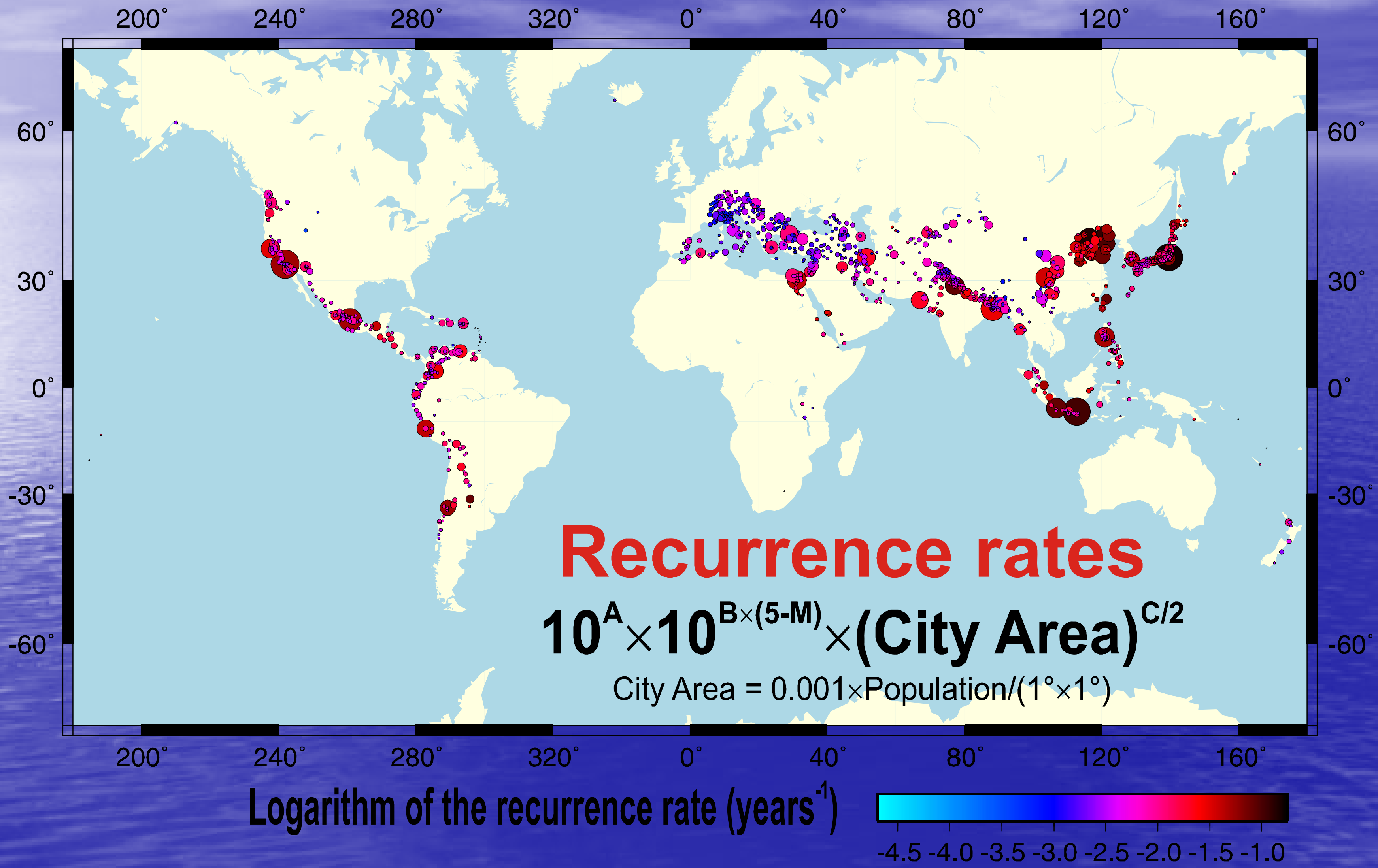
Convolving Seismic Hazard with Object of Risk and its Vulnerability provides an estimation of Seismic Risk



To avoid misleading counterproductive interpretations, we have to emphasize that risk estimates presented here are rather synthetic, given for methodological purposes. The estimations addressing more realistic and practical kinds of seismic risk, not presented here, should involve experts in distribution of objects of risk of different vulnerability, i.e., specialists in earthquake engineering, social sciences and economics.

Strong, magnitude 6, earthquakes.

Synthetic estimation for educational purposes only.



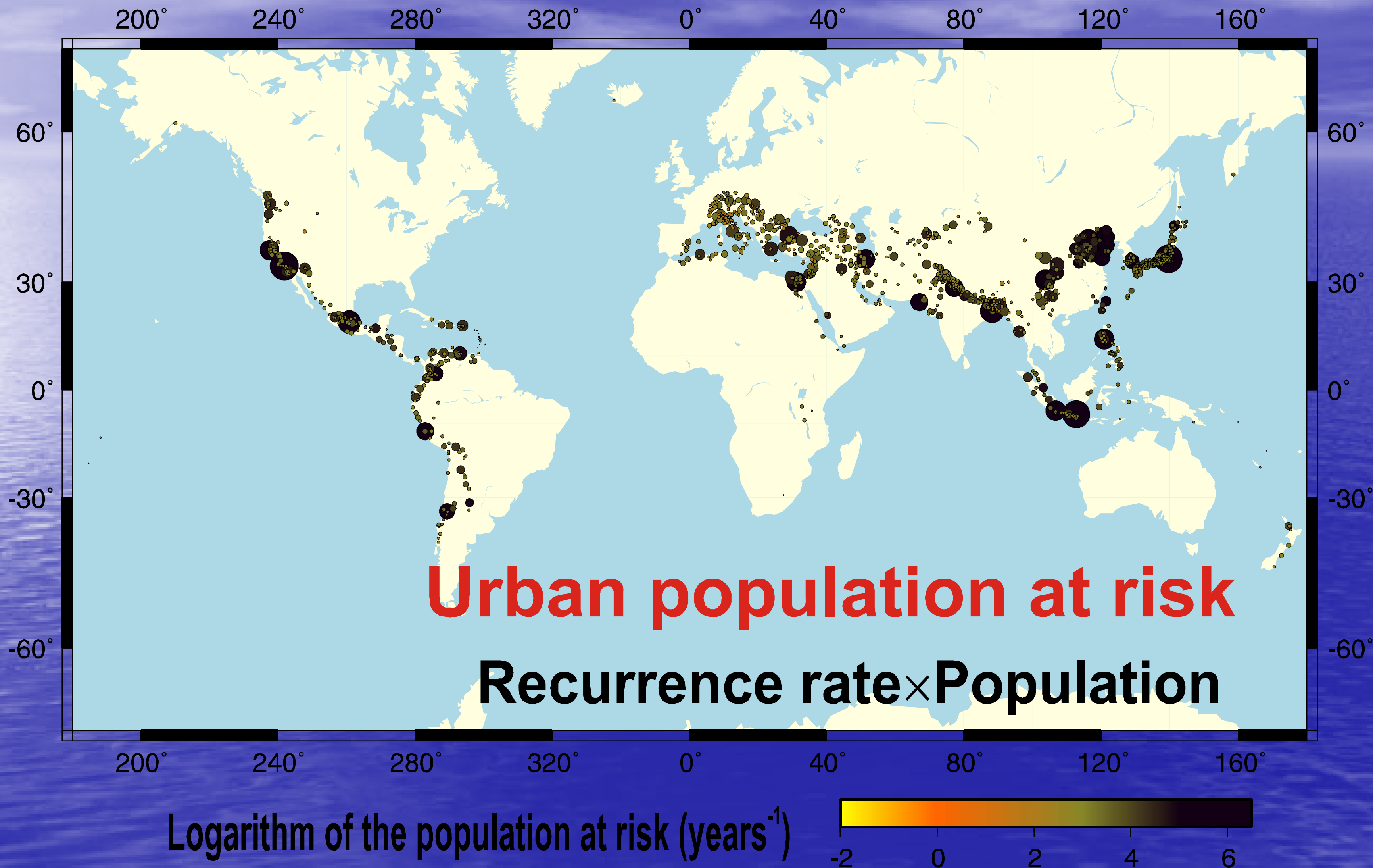
Synthetic estimation for educational purposes only.

Top ten* recurrence rates for strong (M6+) earthquakes

City	Country	Population	A	B	C	Recurrence rate, $years^{-1}$
Tokyo	Japan	11,906,331	0.14	0.94	1.34	0.15663
Taipei	China	1,769,568	0.22	0.80	1.15	0.08580
Jakarta	Indonesia	6,503,449	0.15	1.06	1.23	0.08349
Kobe	Japan	1,422,922	0.17	0.90	0.84	0.07368
Yokohama	Japan	3,049,782	0.15	0.95	1.32	0.06258
Kyoto	Japan	1,480,355	0.16	0.93	0.96	0.06177
Santiago	Chile	4,099,714	0.08	1.05	1.21	0.05579
Quanzhou	China	403,180	0.39	0.95	0.96	0.05310
Los Angeles	US	13,074,800	-0.34	0.95	1.19	0.05267
Gaoxiong	China	828,191	0.21	0.80	1.18	0.05165

Strong, magnitude 6, earthquakes.

Synthetic estimation for educational purposes only.



Synthetic estimation for educational purposes only.

Top ten* of the population at risk for strong (M6+) earthquakes

City	Country	Population	A	B	C	Population at risk, year^{-1}
Tokyo	Japan	11,906,331	0.14	0.94	1.34	1,864,928
Los Angeles	US	13,074,800	-0.34	0.95	1.19	688,671
Jakarta	Indonesia	6,503,449	0.15	1.06	1.23	543,000
Mexico	Mexico	8,831,079	-0.16	1.05	1.24	444,839
Manila	Philippines	6,720,050	0.03	1.16	1.35	325,408
Santiago	Chile	4,099,714	0.08	1.05	1.21	228,741
Lima	Peru	5,008,400	-0.26	0.86	1.36	204,522
Yokohama	Japan	3,049,782	0.15	0.95	1.32	190,865
San Francisco	US	5,877,800	-0.38	0.93	1.20	183,198
Taipei	China	1,769,568	0.22	0.80	1.15	151,830

Maximum intensity maps

One can use the long-term estimates of the USLE coefficients to characterize seismic hazard in traditional terms of maximum expected intensity. Specifically, consider the values of A, B, and C obtained for grid points of a regular $l \times l$ mesh.

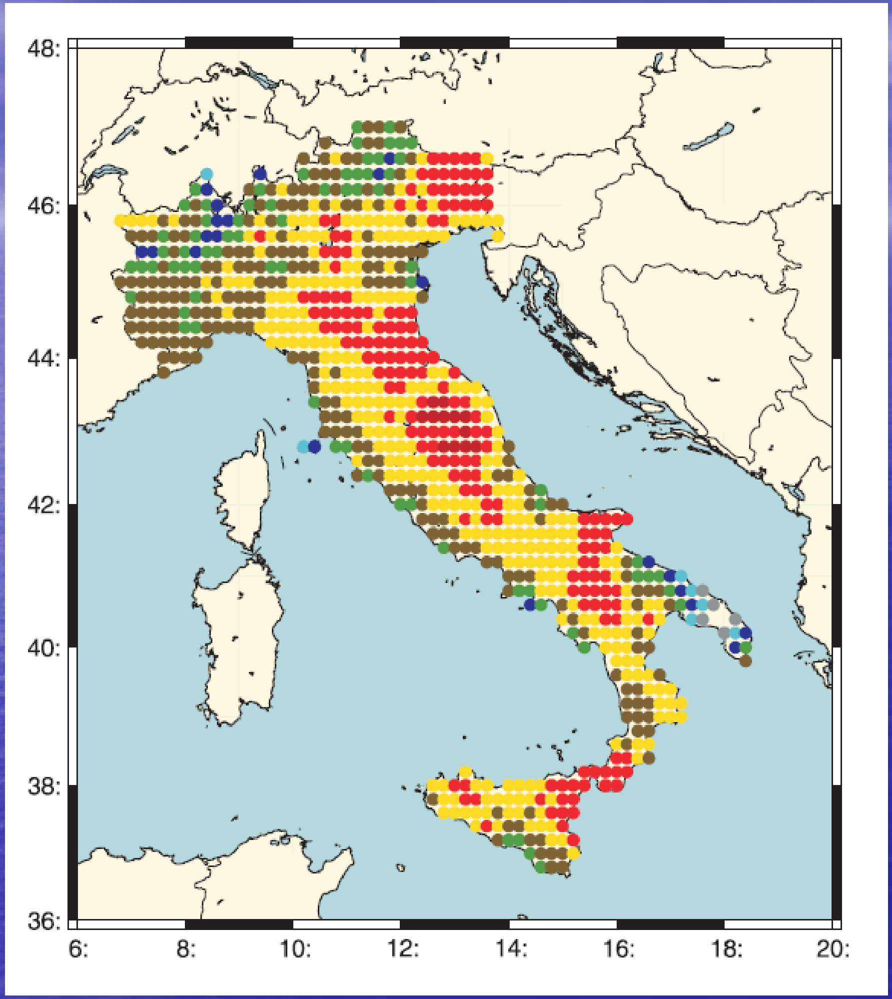
Using formula Log N(M,L) = A + B·(5 - M) + C·Log L, **for magnitude ranges from M1 to M2 with 0.5-magnitude step we have calculated the expected number of events in T years N_T (M)= T $\times$ N(M).**

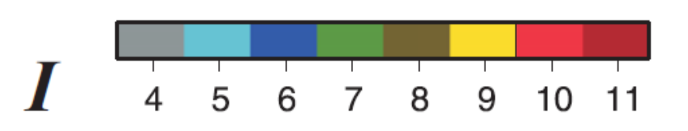
For each cell we find the maximum magnitude with the expected number N_T(M) = p% or greater and assign the intensity that corresponds to this maximum magnitude.

Presumably, the intensity assigned to a cell indicates the maximum one with probability of exceedance of p% in T years.

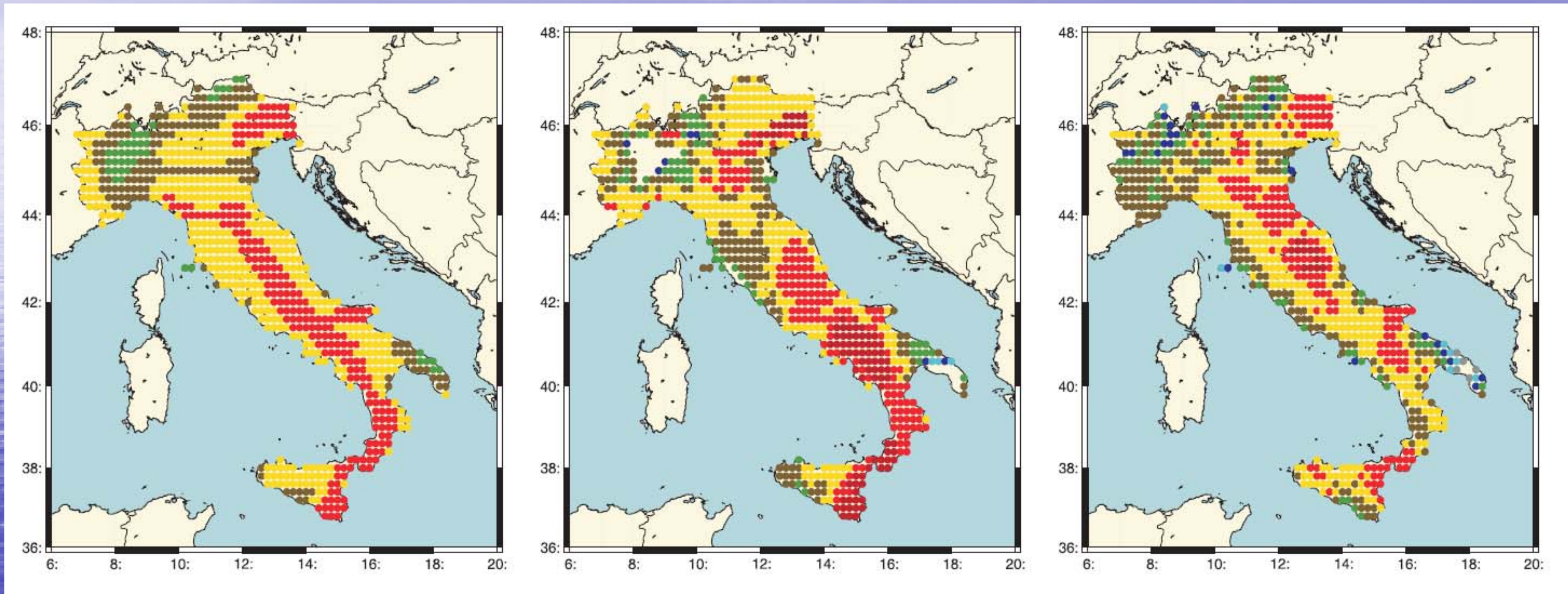
M	4	4.5	5	5.5	6	6.5	7.0
I	V	VI	VII	VIII	IX	X	XI

Italy, p=10%, T=50 years, *l*=0.2°

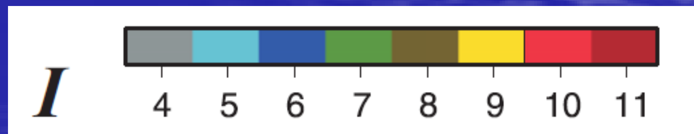




Comparison of traditional PSHA to neo-deterministic and USLE-based seismic hazard assessment



PSHA **NDPSH** **USLE**



Conclusions

The evident heterogeneity of patterns of seismic distribution and dynamics are apparently scalable according to the generalized Gutenberg-Richter recurrence law that accounts for the fractal nature of faulting. The results of our global and regional analyses imply

(i) the recurrence of earthquakes in a seismic region, for a wide range of magnitudes and sizes, can be characterized with the following law:

$$\text{Log } N(M,L) = A + B\cdot(5 - M) + C\cdot\text{Log } L,$$

where N(M,L) is the expected annual number of main shocks of magnitude M within an earthquake-prone area of liner size L

(ii) for a wide range of seismic activity, A, the balance between magnitude ranges, B, varies from 0.6 to 1.4, while the fractal dimension, C, changes from under 1 to 1.6

(iii) an estimate of earthquake recurrence rate depends on the size of the territory that is used for averaging and may differ dramatically when rescaled in traditional way to the area of interest.

The confirmed multiplicative scaling of earthquakes changes the traditional view on their recurrence, the catastrophic ones in particular, and has serious implications for estimation of seismic hazard, for the Seismic Risk Assessment, as well as for earthquake prediction.

The observed temporal variability of the USLE coefficients suggests investigating predictive power and efficiency of some *ABC* –related patterns with more data accumulated worldwide in the future. Such patterns, if confirmed in testing, might indicate the transient “lock-unlock” status of the faults in the system of blocks-and-faults, however, it appears yet premature to come out with an algorithmic formulation.

Finally, let me beware again on a synthetic character of seismic risk assessments presented in this talk for illustrative purposes only.

Thus, earthquake mitigation measures in areas where large earthquakes are possible may not be based on GSHAP maps. It follows that the international project Global Earthquake Model, GEM, (http://www.globalquakemodel.org/) is on the wrong track, if it continues to base seismic risk estimates on the standard method when many reasons have been given to abandon it.

Advanced Seismic Hazard Assessment,

Eds. G. Panza, K. Irikura, M. Kouteva-Guentcheva, A. Peresan, Z. Wang, R. Saragoni.

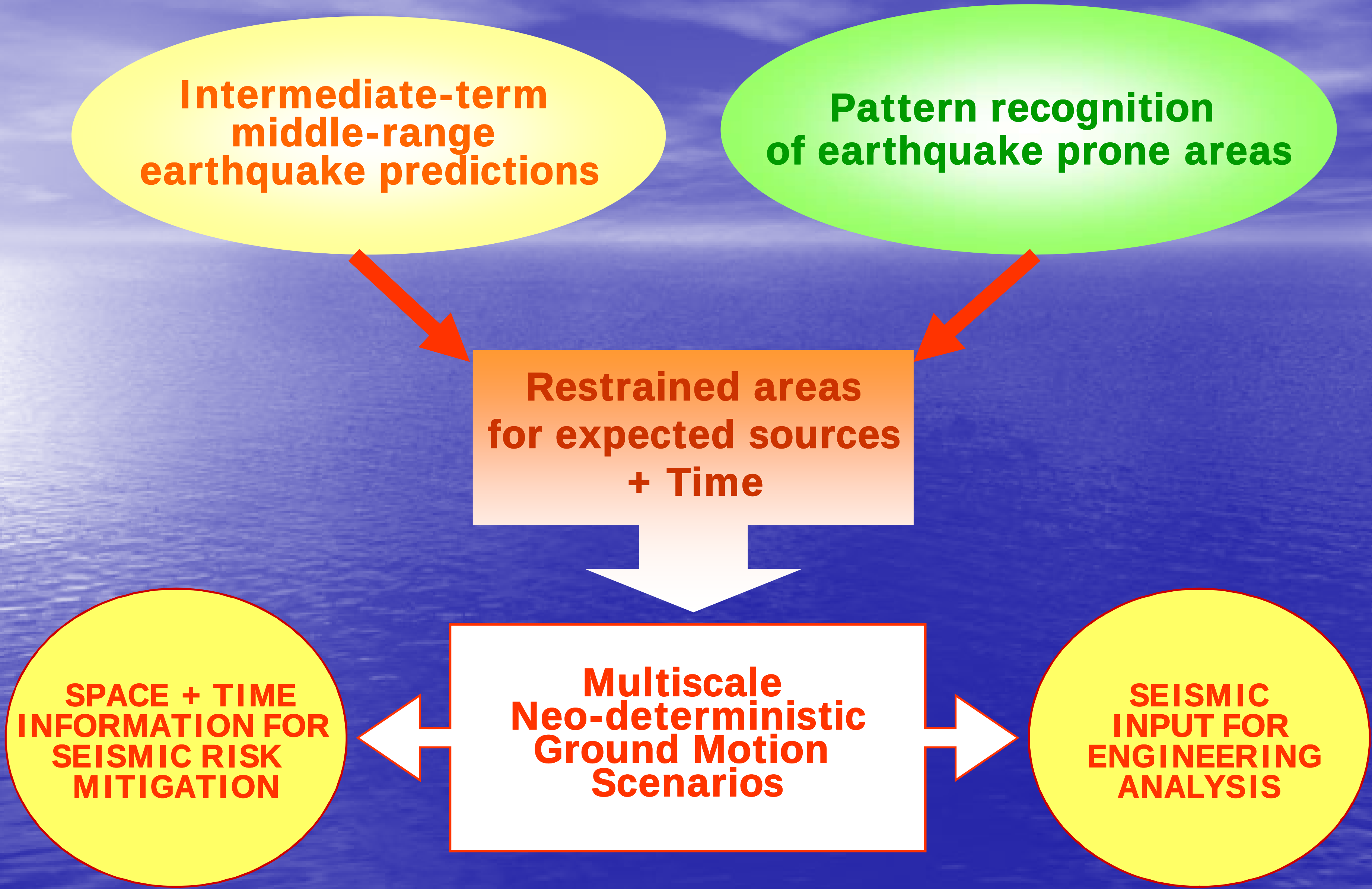
Pure Appl. Geophys. ***168 (1-4), 1–752. (2011).***

Modern methods for modeling realistic scenarios of earthquakes allow better assessment of current seismic hazard

Advanced Seismic Hazard Assessment,

Eds. G. Panza, K. Irikura, M. Kouteva-Guentcheva, A. Peresan, Z. Wang, R. Saragoni.

Pure Appl. Geophys. ***168 (1-4), 1–752. (2011).***


Intermediate-term
middle-range
earthquake predictions
Pattern recognition
of earthquake prone areas
Restrained areas
for expected sources
+ Time
SPACE + TIME
INFORMATION FOR
SEISMIC RISK
MITIGATION
Multiscale
Neo-deterministic
Ground Motion
Scenarios
SEISMIC
INPUT FOR
ENGINEERING
ANALYSIS

Multiscale Neo-deterministic Hazard Scenarios

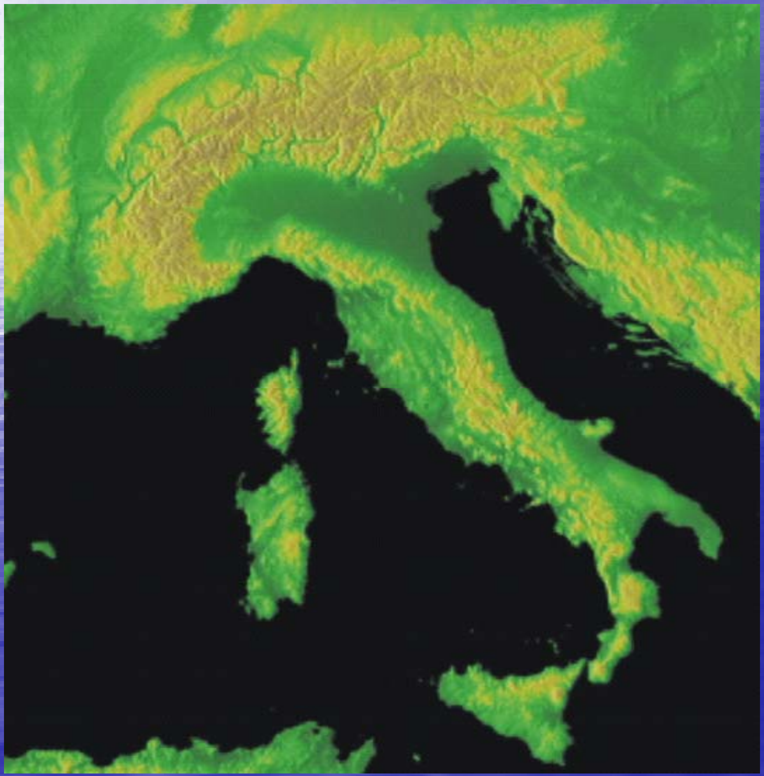
Regional, site specific, seismic hazard scenarios

(ground motion at bedrock)

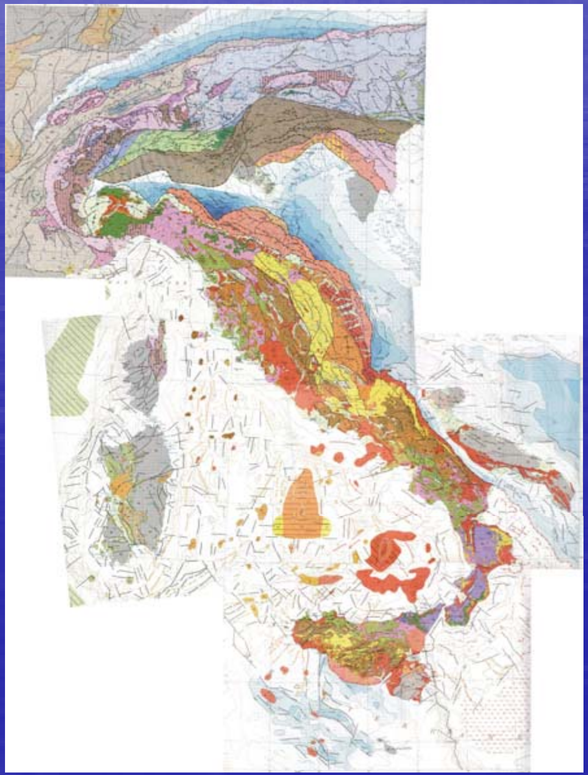
associated to seismogenic nodes (D-intersections)
and/or
associated to those in the alerted areas (of TIPs)

Initial data for morphostructural zoning

Topography



Tectonic structure



Satellite photos

RECOGNITION OF EARTHQUAKE PRONE AREAS

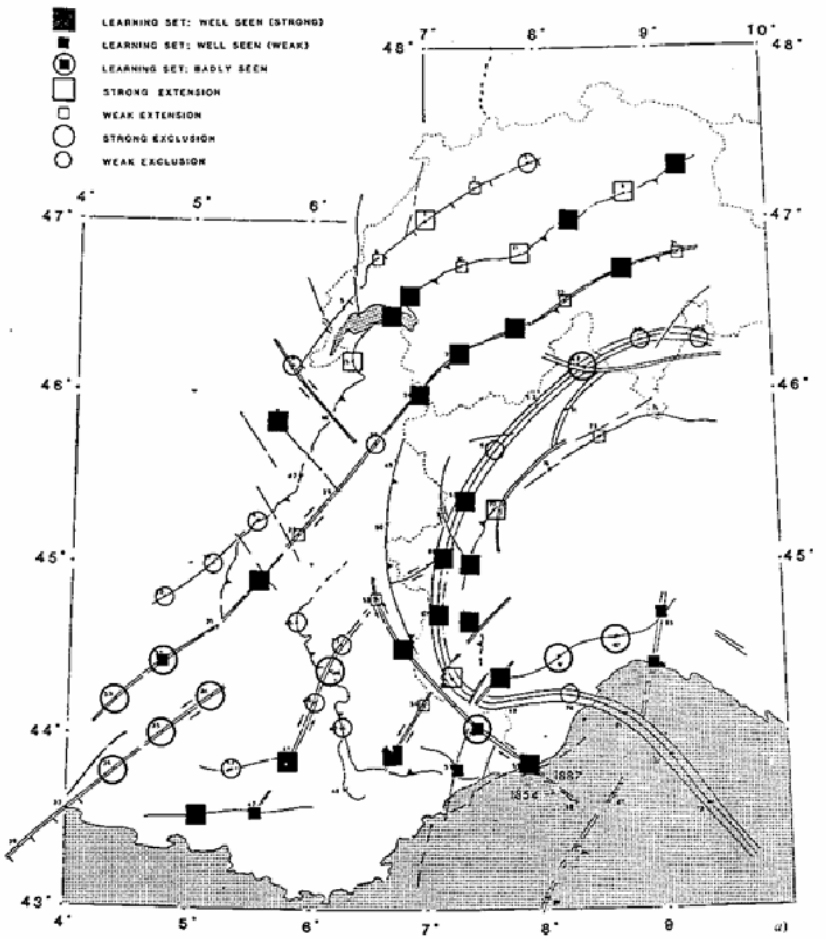
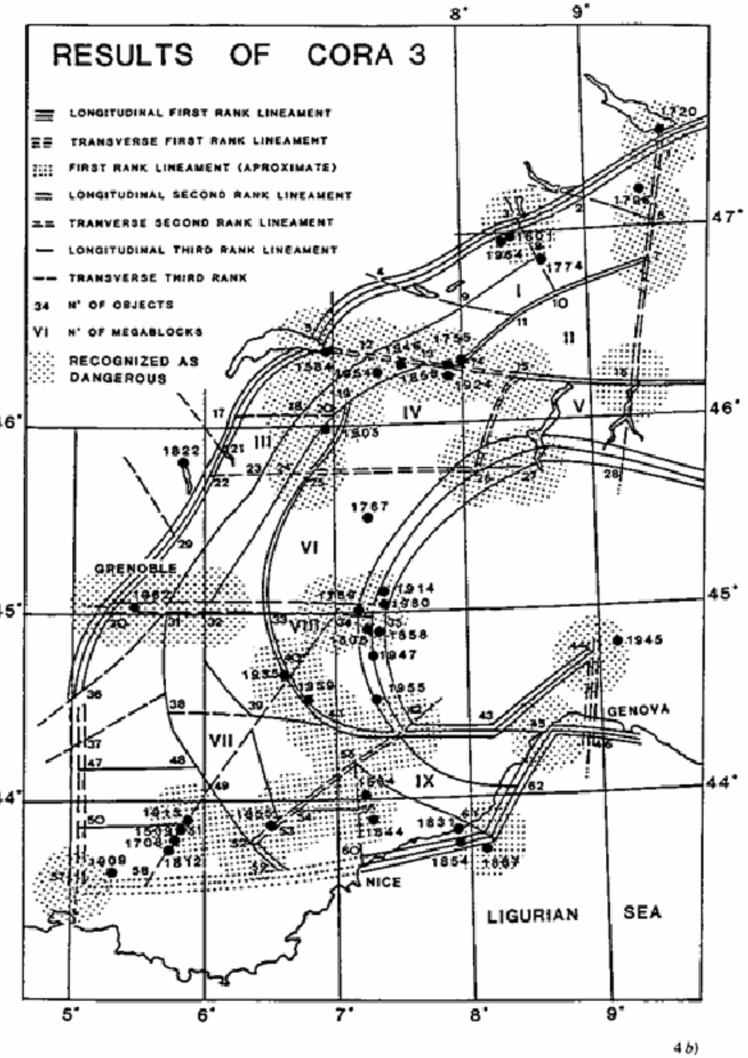


Figure 4

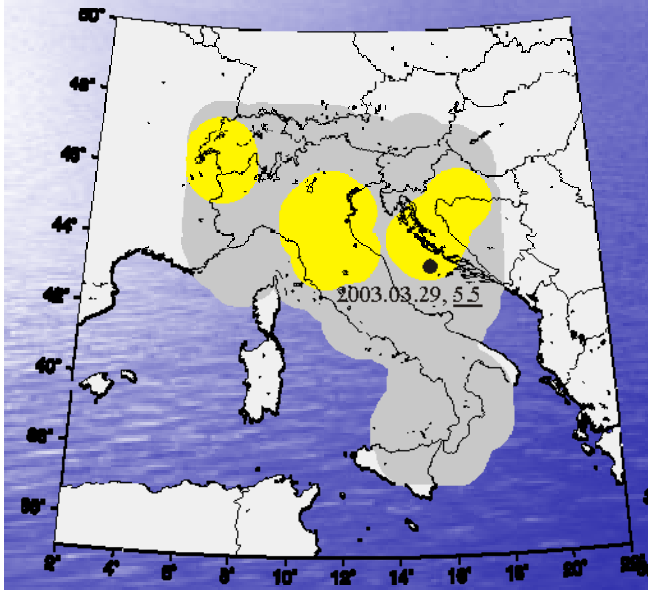
Results of Recognition. a) Experts Communication method over Neotectonic Scheme. Symbols indicate : the learning set (dark squares), the extension by learning (open squares) and the nondangerous objects (circles). Some specification about the way the algorithm sees the objects is included (strong or weak assimilation and exclusion). b) CORA-3 generalisation of the concept of dangerous objects and the epicenters of earthquakes from table 1. Dangerous areas are the 25 km radius disks.

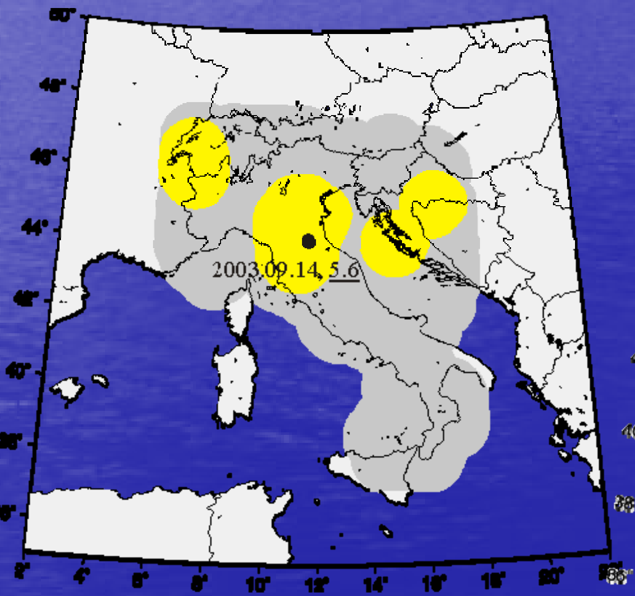
RECOGNITION OF EARTHQUAKE PRONE AREAS

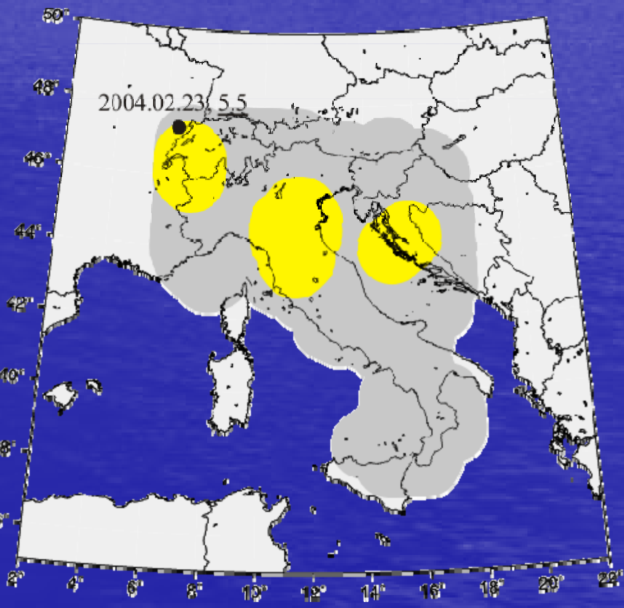


Cisternas, A., B.P. Godefroy, A.D. Gvishiani, A.A. Soloviev, A.I. Gorshkov, V.G. Kosobokov, M. Lambert, E.I. Rantzman, J. Sallantin, A. Soldano, C. Weber, 1985. A Dual Approach to Recognition of Earthquake prone Areas in the Western Alps. *Annales Geophysicae*, **3**, No. 2, 249-270

The targeting smaller magnitude earthquakes at regional scales may require application of a recently proposed scheme for the spatial stabilization of the intermediate-term middle-range predictions. The scheme guarantees a more objective and reliable diagnosis of times of increased probability and is less restrictive to input seismic data.

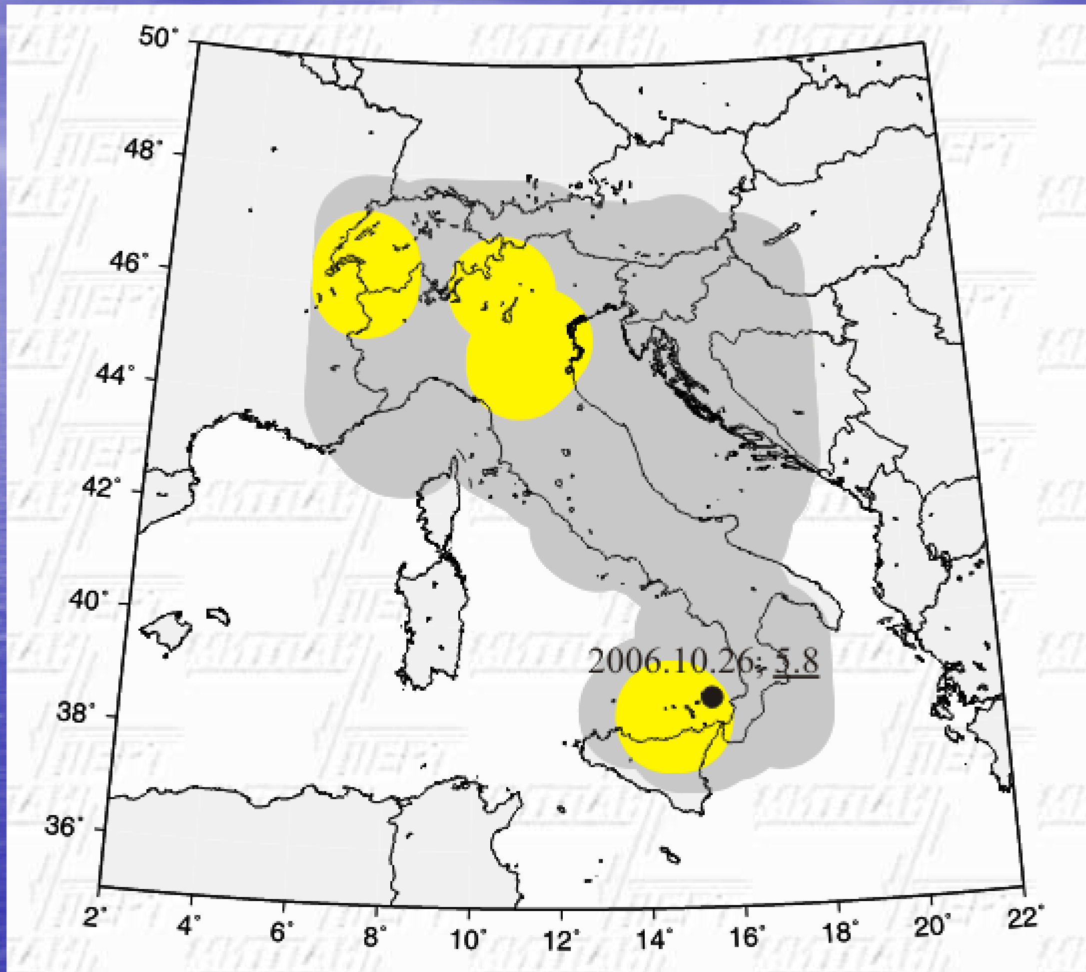






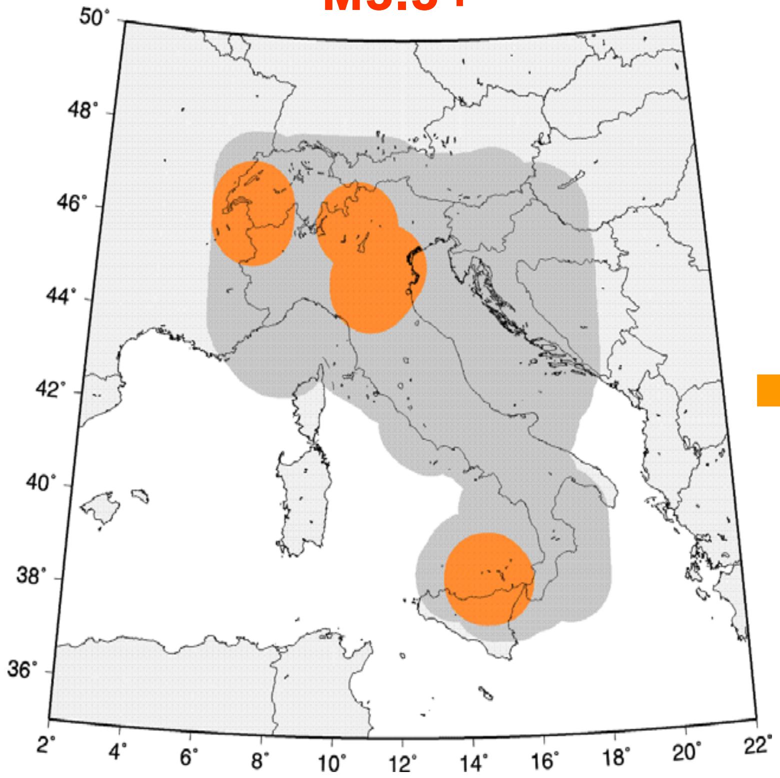
The M8S was designed originally

to improve reliability of predictions made by the modified versions of the M8 algorithm applicable in the areas of deficient earthquake data available.

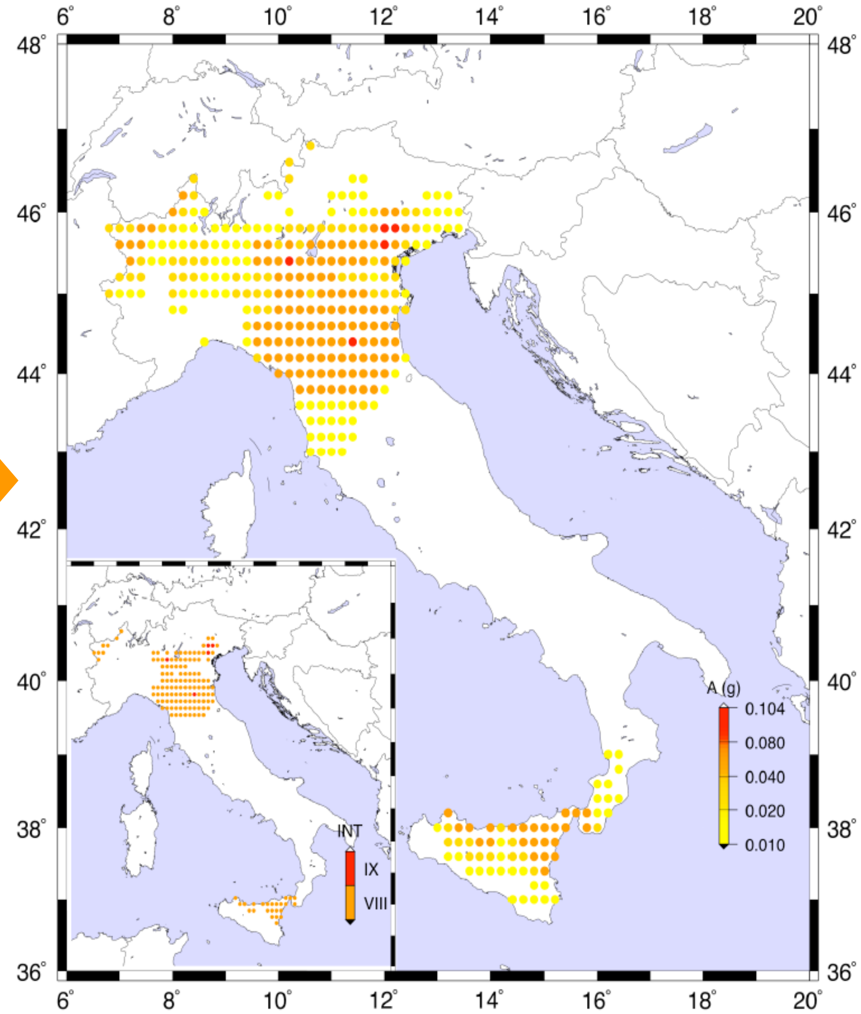

50°
48°
46°
44°
42°
40°
38°
36°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
22°
2006.10.26; 5.8

Neo-deterministic hazard scenarios associated to alerted regions: M8S algorithm

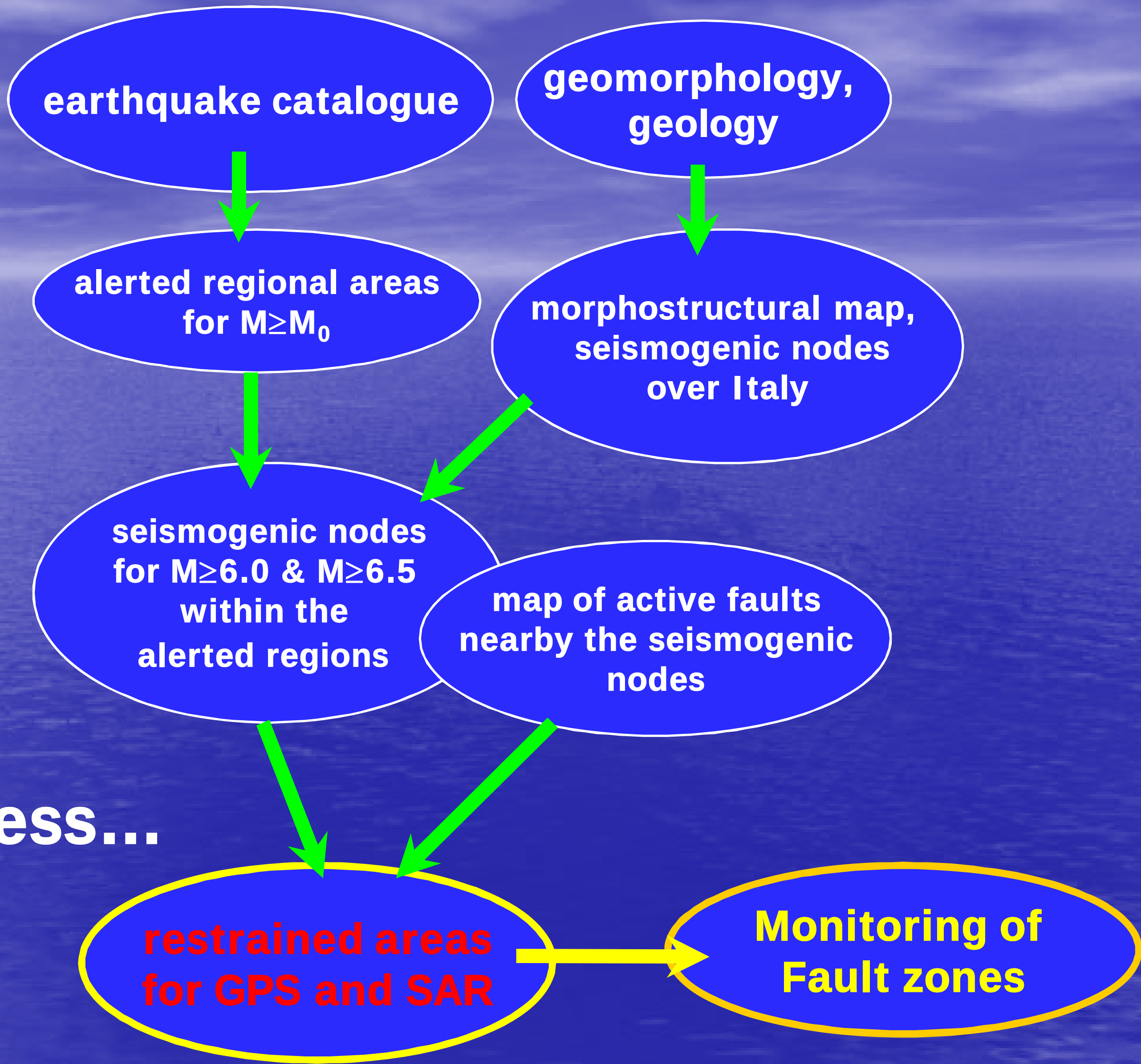
Prediction of earthquakes with M5.5+



Alerted areas by M8S algorithm
for an earthquake with 5.5≤M<6.0
(as on 1 July 2006 – 1 January 2007)



Integration with geodetic observations



Work in progress…

ASI Pilot Project - SISMA

"Seismic Information System for Monitoring and Alert"

Development of a fully formalized system integrating the space and time dependent information provided by CN and M8S real-time monitoring of seismic flow and EO data analysis, through geophysical forward modeling.

Routinely updated CN and M8S predictions are made available to the Civil Defence of the Friuli Venezia Giulia Region (NE Italy)

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University of Milano

Politecnico di Milano

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**

Final remarks

I.M. Gelfand
(1913-2009)

Izrail M. Gelfand, Two archetypes in the psychology of Man.
Nonlinear Sci. Today 1 (1991), no. 4, 11
The Inamori Foundation Kyoto Prize Commemorative lecture
of the 1989 Laureate in Basic Sciences

I would like to recall what was said as a casual remark before. Mathematics is an area in which two types of thinking collide - artistic and precise, logical; and this unique alloy makes mathematics an area, which occupies a special place in human culture. Perhaps the only music can compete with it.

Izrail M. Gelfand, Two archetypes in the psychology of Man.
Nonlinear Sci. Today 1 (1991), no. 4, 11
The Inamori Foundation Kyoto Prize Commemorative lecture
of the 1989 Laureate in Basic Sciences

7. Liability of mathematicians.

I would like to say a few words about the moral responsibility of mathematicians.

Mathematics is one of the highest achievements of the human spirit and at the same time, a very accurate and adequate language, without which the physics and many other fields would have been impossible. And the first side of liability of mathematicians is of using the experience and achievements of mathematics, especially mathematics of XX century, to expand significantly an opportunity for creating adequate languages in other branches of science. First and foremost, to help in identifying the structures and, if possible, to develop an adequate language for living systems - various areas of biology, economics, psychology, etc.

I am an optimist and I believe that nowadays in this not much advanced direction much will be done, especially in the times of computers, which are slowly but inevitably will change the psychology of mathematicians, forcing them to recall non-formalizable living systems.

…

Izrail M. Gelfand, Two archetypes in the psychology of Man.
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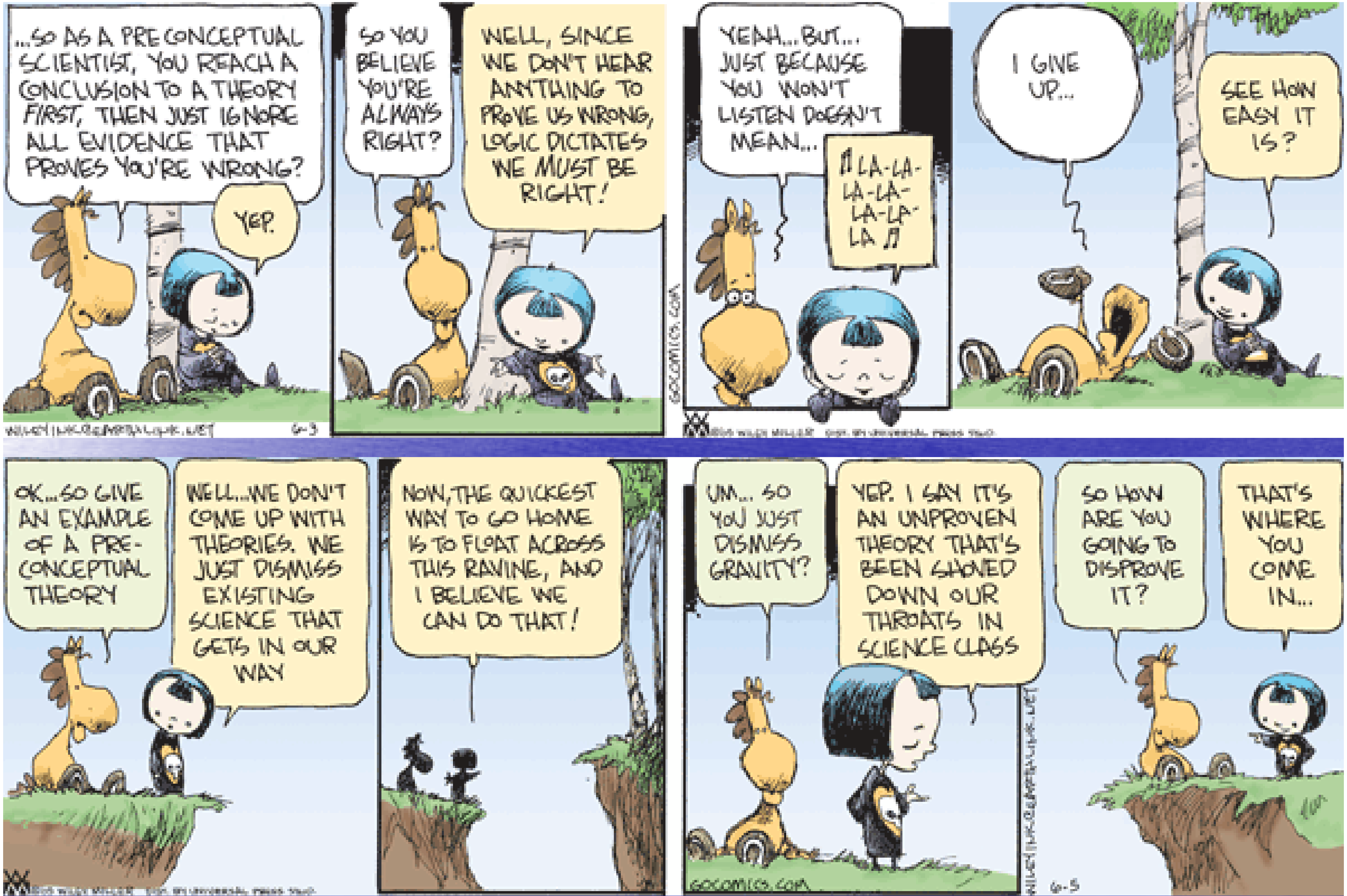
7. Liability of mathematicians.

…

But perhaps even more responsibility, as I have said, is to counter the unwise and dangerous use of precise mathematical and logical systems outside their applicability. Despite the fact that I gave this little room here, I see it as an important issue, which should be dealt with in a separate dedicated report. For who but mathematicians can help preventing abuse of mathematics in our technocratic age.

Beware of the product designs by preconceptionalists!

"I'm arresting you for bringing the Emperor into disrepute."


...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?
OK... SO GIVE AN EXAMPLE OF A PRE-CONCEPTUAL THEORY
WELL... WE DON'T COME UP WITH THEORIES. WE JUST DISMISS EXISTING SCIENCE THAT GETS IN OUR WAY
NOW, THE QUICKEST WAY TO GO HOME IS TO FLOAT ACROSS THIS RAVINE, AND I BELIEVE WE CAN DO THAT!
UM... SO YOU JUST DISMISS GRAVITY?
YEP. I SAY IT'S AN UNPROVEN THEORY THAT'S BEEN SHOVED DOWN OUR THROATS IN SCIENCE CLASS
SO HOW ARE YOU GOING TO DISPROVE IT?
THAT'S WHERE YOU COME IN...
GOCOMICS.COM

Thank you!

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