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«NON-LIINEAR MATHEMATICAL PHYSICS AND NATURAL HAZARDS»

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Predicting Earthquakes and Related Ground Shaking: Testing and Validation Issues

A. Peresan

A. Nekrasova, V. Kossobokov, G.F. Panza

UNIVERSITÀ DEGLI STUDI DI TRIESTE
Department of Mathematics and Geosciences

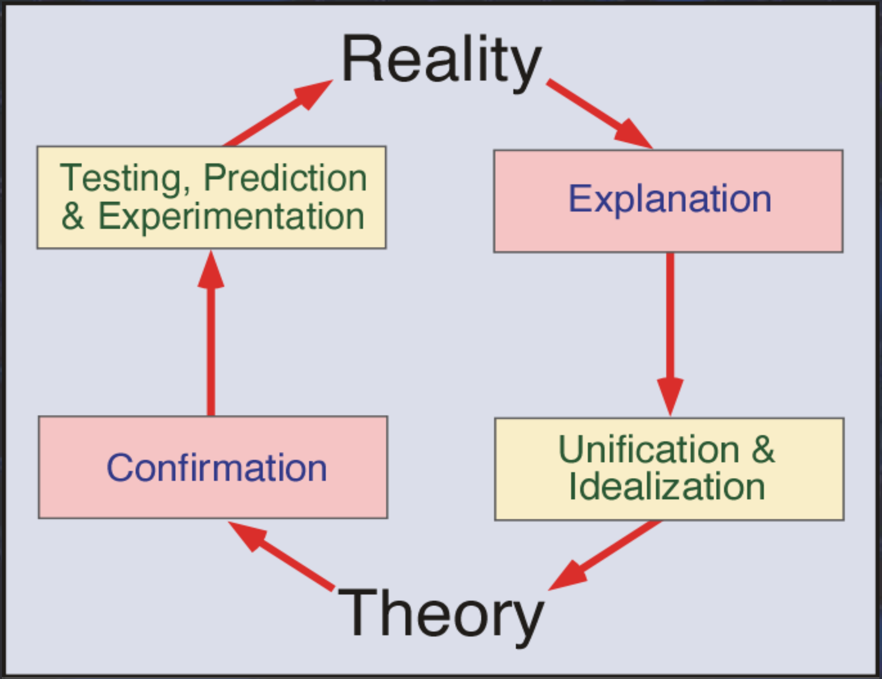
The Abdus Salam International Centre for Theoretical Physics

ICTP – SAND Group
and Department of
Mathematics and Geosciences
University of Trieste
Via Weiss 4, 34127
Trieste - Italy
aperesan@units.it

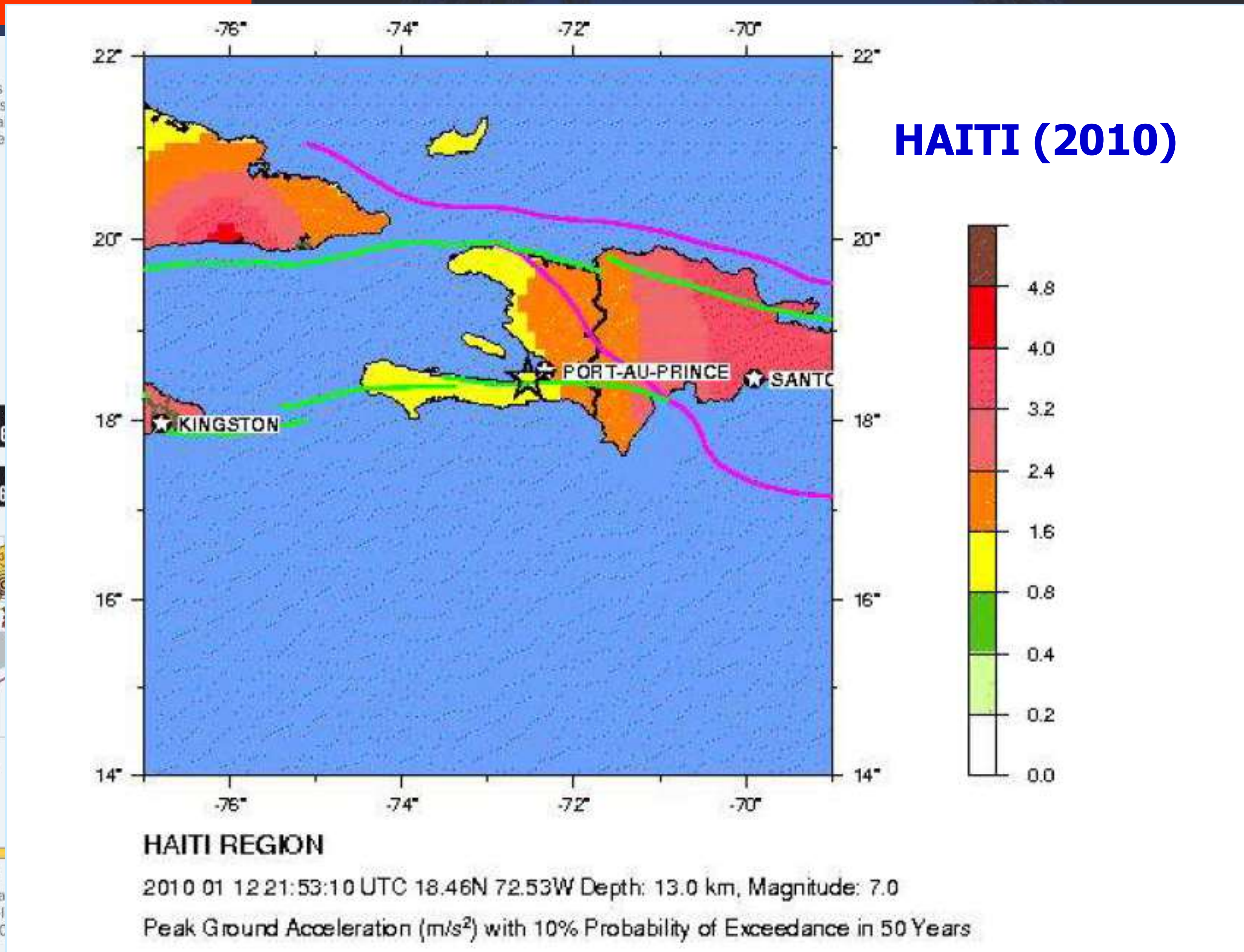
The scientific method

- Idealization is the condensation of a body of empirical facts into a simple statement => abstract representation of the processes and phenomenon => omitting details and isolating the phenomenon from other aspects of the system of interest.
- A second aspect of explanation is the unification of apparently unrelated phenomena in the same abstract or ideal system.

- **Confirmation is accomplished through hypothesis testing, prediction, and by running experiments.**



Testing seismic hazard maps



List of the deadliest earthquakes occurred since 2000

Most of them were underestimated by traditional probabilistic ground shaking estimates (GSHAP) => Need for objective testing of SHA

Region	Date	Magnitude	Fatalities	Intensity difference
Sumatra-Andaman "Indian Ocean Disaster"	26.12.2004	9.0	227898	4.0 (IV)
Port-au-Prince (Haiti)	12.01.2010	7.3	222570	2.2 (II)
Wenchuan (Sichuan, China)	12.05.2008	8.1	87587	3.2 (III)
Kashmir (North India and Pakistan border region)	08.10.2005	7.7	~86000	2.3 (II)
Bam (Iran)	26.12.2003	6.6	~31000	0.2 (=)
Bhuj (Gujarat, India)	26.01.2001	8.0	20085	2.9 (III)
Off the Pacific coast of Tōhoku (Japan)	11.03.2011	9.0	15811 (4035 missing)*	3.2 (III)
Yogyakarta (Java, Indonesia)	26.05.2006	6.3	5749	0.3 (=)
Southern Qinghai (China)	13.04.2010	7.0	2698	2.1 (II)
Boumerdes (Algeria)	21.05.2003	6.8	2266	2.1 (II)
Nias (Sumatra, Indonesia)	28.03.2005	8.6	1313	3.3 (III)
Padang (Southern Sumatra, Indonesia)	30.09.2009	7.5	1117	1.8 (II)

Intensity difference among the observed values and those predicted by GSHAP

Kossobokov & Nekrasova (AGU, 2011)
Wyss, Kossobokov & Nekrasova (Nat.Haz., 2012)

Testing seismic hazard maps

PUBLICATIONS: SRL: OPINION

OPINION

September/October 2011

Bad Assumptions or Bad Luck: Why Earthquake Hazard Maps Need Objective Testing

doi:10.1785/gssrl.82.5.623

Bad assumptions or bad luck: why earthquake hazard maps need objective testing

Seth Stein
Robert Geller
Mian Liu

Seism. Res. Lett., 82:5
September – October 2011

In the above cases, the maps significantly underpredicted the earthquake hazard. However, their makers might argue that because the maps predict the maximum shaking expected with some probability in some time interval, the much larger earthquakes and resulting shaking that actually occurred are rare events that should not be used to judge the maps as unsuccessful. So how should we judge a map's performance? Currently, there are no generally agreed upon criteria. It is surprising that although such hazard maps are widely used in many countries, their results have never been objectively tested.

Testing seismic hazard maps

Conclusions:

the comparison between observations and predictions can provide only limited constraints on probabilistic seismic hazard estimates. This is particularly true for ground accelerations above 0.1g (relevant for strucural damage)

Bulletin of the Seismological Society of America, Vol. 98, No. 2, pp. 509–520, April 2008, doi: 10.1785/0120070006

Can Strong-Motion Observations be Used to Constrain Probabilistic Seismic-Hazard Estimates?

by C. Beauval, P.-Y. Bard, S. Hainzl, and P. Guéguen

Abstract Because of the new regulatory requirements that hazards have to be estimated in probabilistic terms, the number of probabilistic hazard studies conducted has recently been increasing. The present study aims at defining the possibilities and limits for comparing predictions from these studies and observations. Comparison tests based directly on the rate of ground-motion occurrences are favored over the rate of earthquake occurrences. Based on the properties of Poisson processes, the minimum time window ensuring reliable occurrence rate estimates at a site is computed and evaluated. For example, for ground motions with a 475-yr return period at a site, a minimal 12,000-yr observation time window is required for estimating the rate with a 20% uncertainty (coefficient of variation: standard deviation divided by the mean). These values are not dependent on the seismicity level of the regions under study. An analysis of recorded ground motions at the stations of the permanent French accelerometer network shows that at best, the occurrence rates can be estimated with an accuracy of 30% for very low acceleration levels (0.0001–0.001g for the station STET). The same analysis, carried out at two stations with longer recording histories and located in higher seismicity regions (Greece and California), provides ground-motion levels up to 0.1g. Therefore, the question posed is can the results of a comparison test at low acceleration levels be generalized to higher acceleration levels, even if using a ground-motion prediction equation uniformly valid for a wide range of accelerations?

ICTP Advanced Conference on
"Seismic Risk Mitigation and Sustainable Development"
Trieste, 10-14 May 2010

PANEL DISCUSSION

Toward validation of SHA

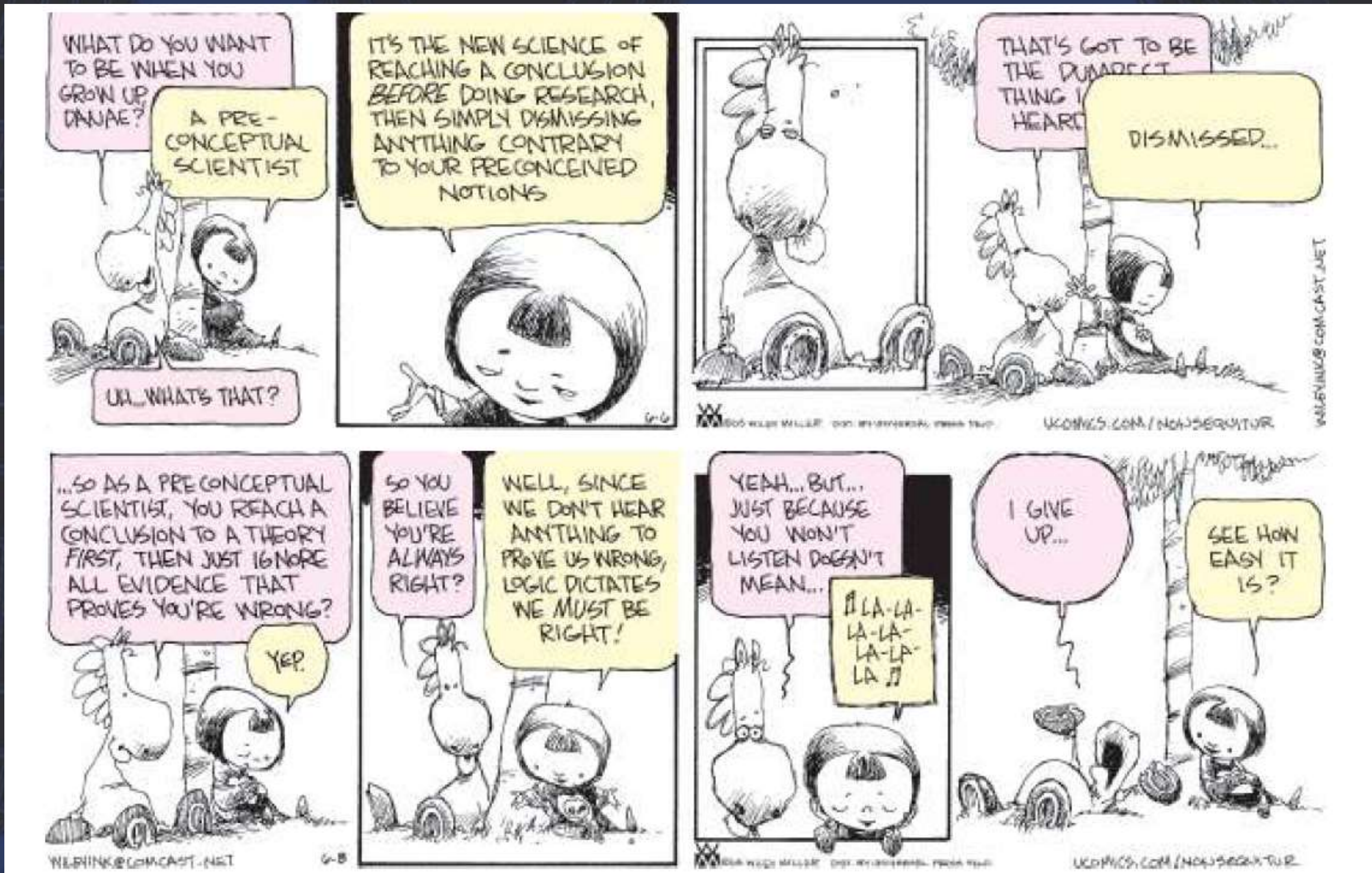
Panelists:
A. Lerner-Lam, V. Kossobokov, Z. Wang, Z. Wu

"SHA models have to be verifiable. But how to verify a SHA model is one of the questions which have to be considered seriously. Comparing the model results against real data is one of the critical steps in the verification. But one needs a clear definition of what is a 'failure' and what is a 'success'."

Recordings using the automated ICTP EyA system are available on the web at: *http://www.ictp.tv/ under the item "Conferences".*

Agenda and Summary report:
http://cdsagenda5.ictp.trieste.it/full_display.php?smr=0&ida=a09145

The scientific method…



Earthquake prediction

Earthquakes cannot be predicted exactly

(i.e. earthquakes can be predicted but not precisely)

What does it means **earthquake prediction**?

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

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

Stages of earthquake prediction

- **The prediction can miss events or have false alarms, but forecasts must demonstrate more predictability than a random guess.**

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

Currently a realistic goal appears to be the middle-range intermediate-term prediction, which involves an area with linear dimension about ten times larger than the linear dimension of the impending event and a time uncertainty of years.

Intermediate-term middle-range earthquake prediction algorithms

CN algorithm (*Gabrielov et al., 1986; Rotwain and Novikova, 1999*)
M8S algorithm (*Keilis-Borok and Kossobokov, 1987; Kossobokov et al., 2002*)

CN and M8S algorithms are based on a set of empirical functions of time to allow for a quantitative analysis of the premonitory patterns which can be detected in the seismic flow:

- **Variations in the seismic activity**
- **Seismic quiescence**
- **Space-time clustering of events**

They allow to identify the TIPs (Times of Increased Probability) for the occurrence of a strong earthquake within a delimited region

Intermediate-term middle-range earthquake prediction algorithms

Main features of CN and M8 algorithms:

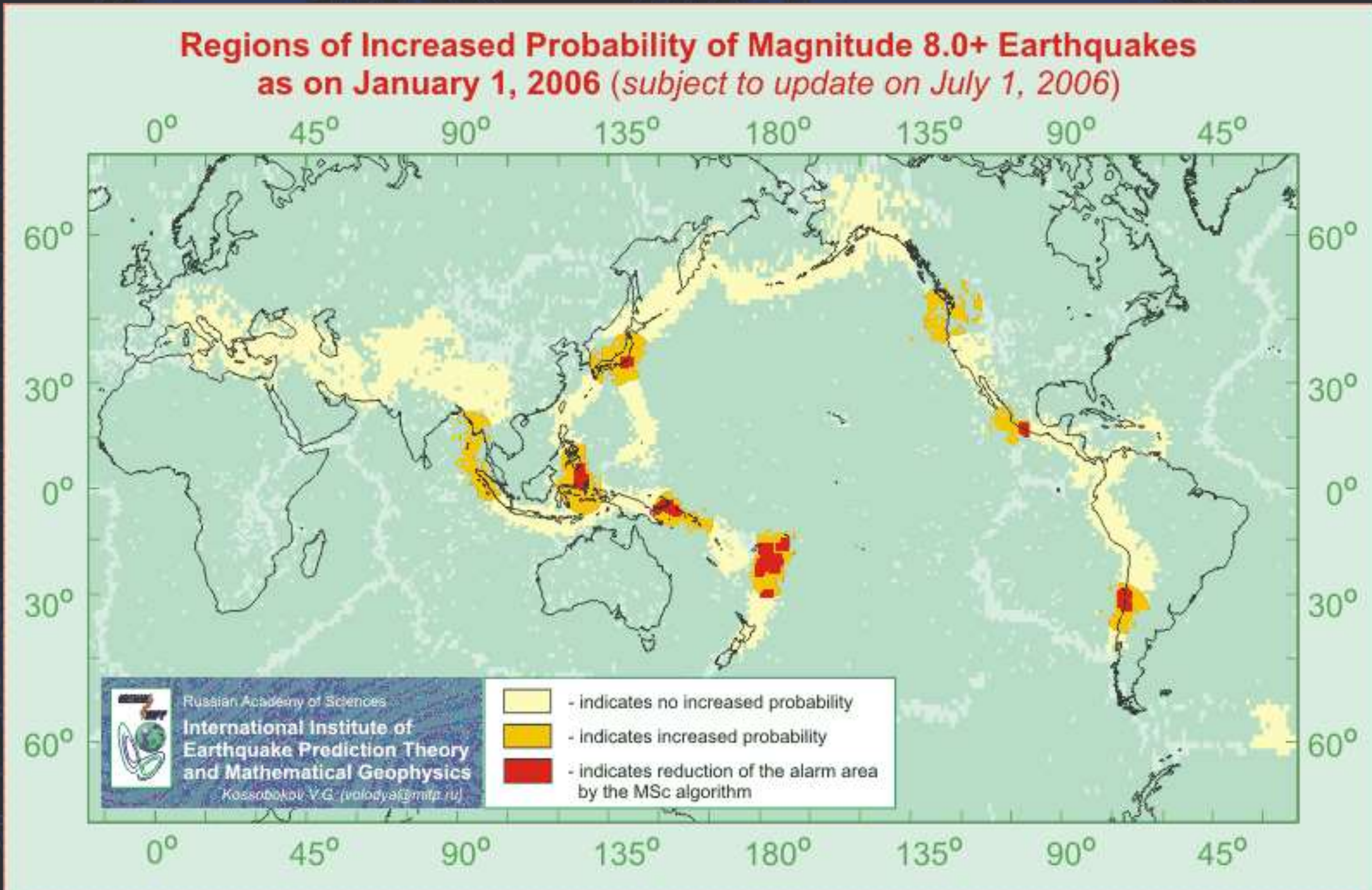
- Fully formalized algorithms and software available for independent testing;
- Use of published & routine catalogs of earthquakes (e.g. NEIC);
- Worldwide tests ongoing for more than 20 years already permitted to assess the significance of the issued predictions.

➡ **Italy: real time earthquake prediction experiment started in July 2003** (*Peresan al., Earth Sci. Rev. 2005*).

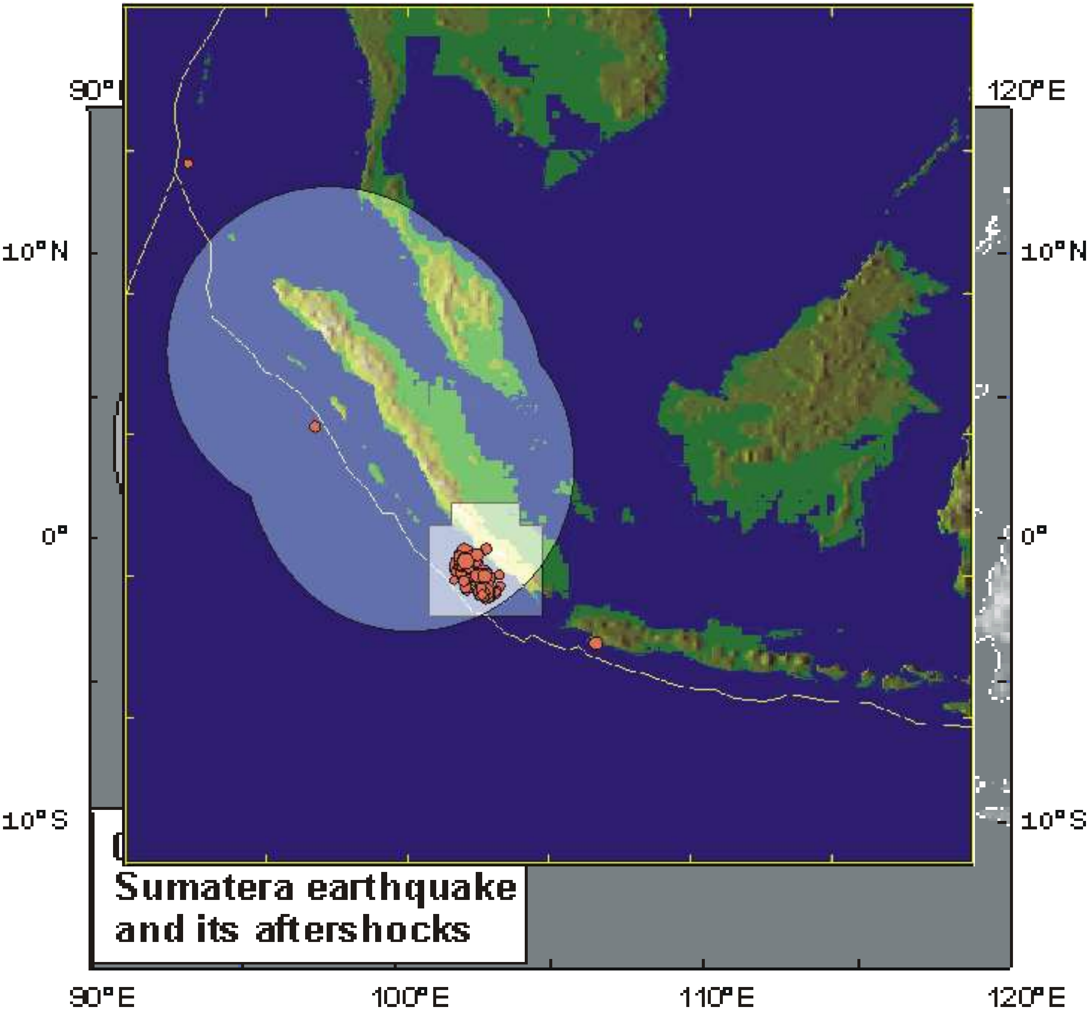
Updated predictions are regularly posted at:
www.ictp.trieste.it/www_users/sand/prediction/prediction.htm
Current predictions are accessible via password only, to prevent improper use of research on earthquake prediction.

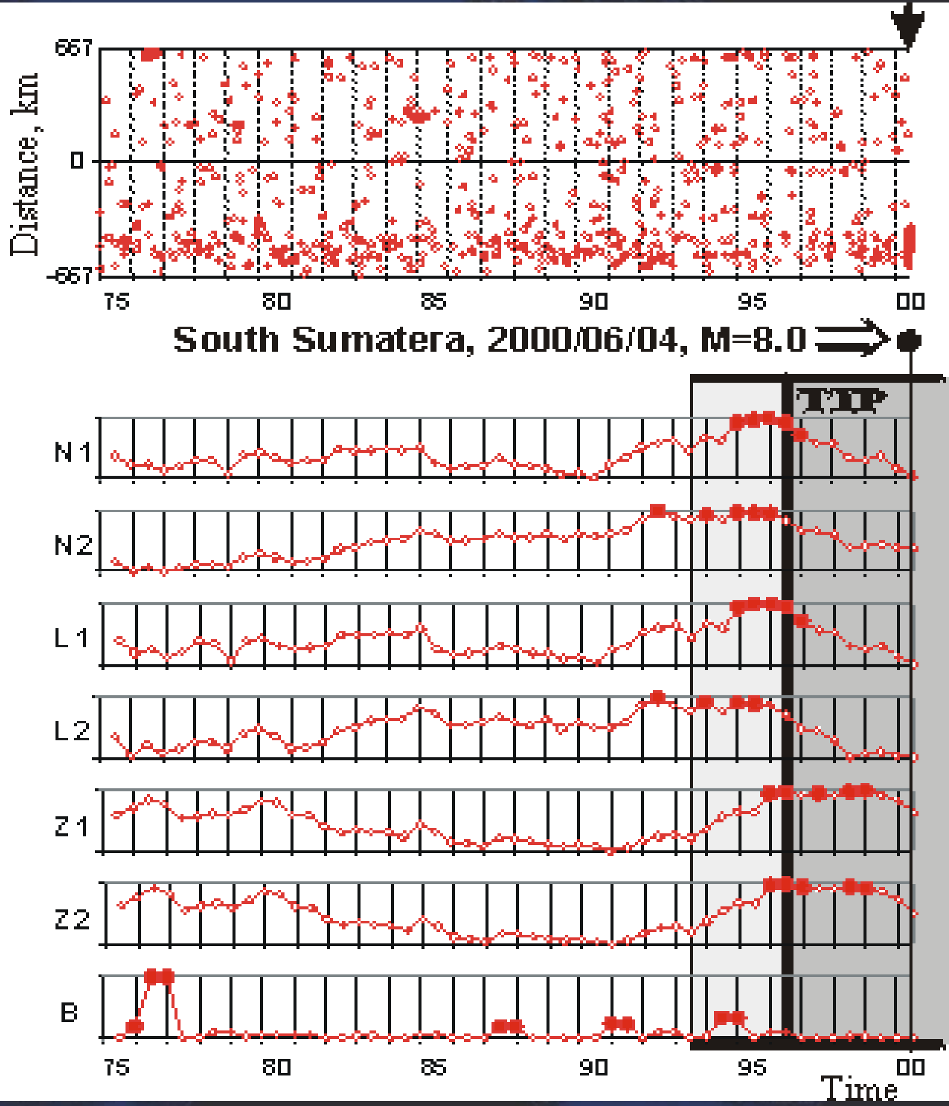
The experiment, ongoing since more than a decade, already allowed to assess the statistical significance of issued predictions.

Worldwide application of the algorithms M8 and M8-MSc: magnitude M8.0+



04/06/2000 South Sumatera Earthquake





Worldwide application of Algorithm M8

The algorithm M8 is applied on a global scale for the prediction of the earthquakes with M8.0+ and M7.5+:

Table 2 Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: magnitude range M8.0+

Test period	Large earthquakes			Measure of alarms, %		Confidence level, %	
	Total	Predicted by		M8	M8-MSc	M8	M8-MSc
		M8	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

Confidence level tells how sure one can be that the achieved performance is not arisen by chance

Table 3 Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: magnitude range M7.5+

Test period	Large 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

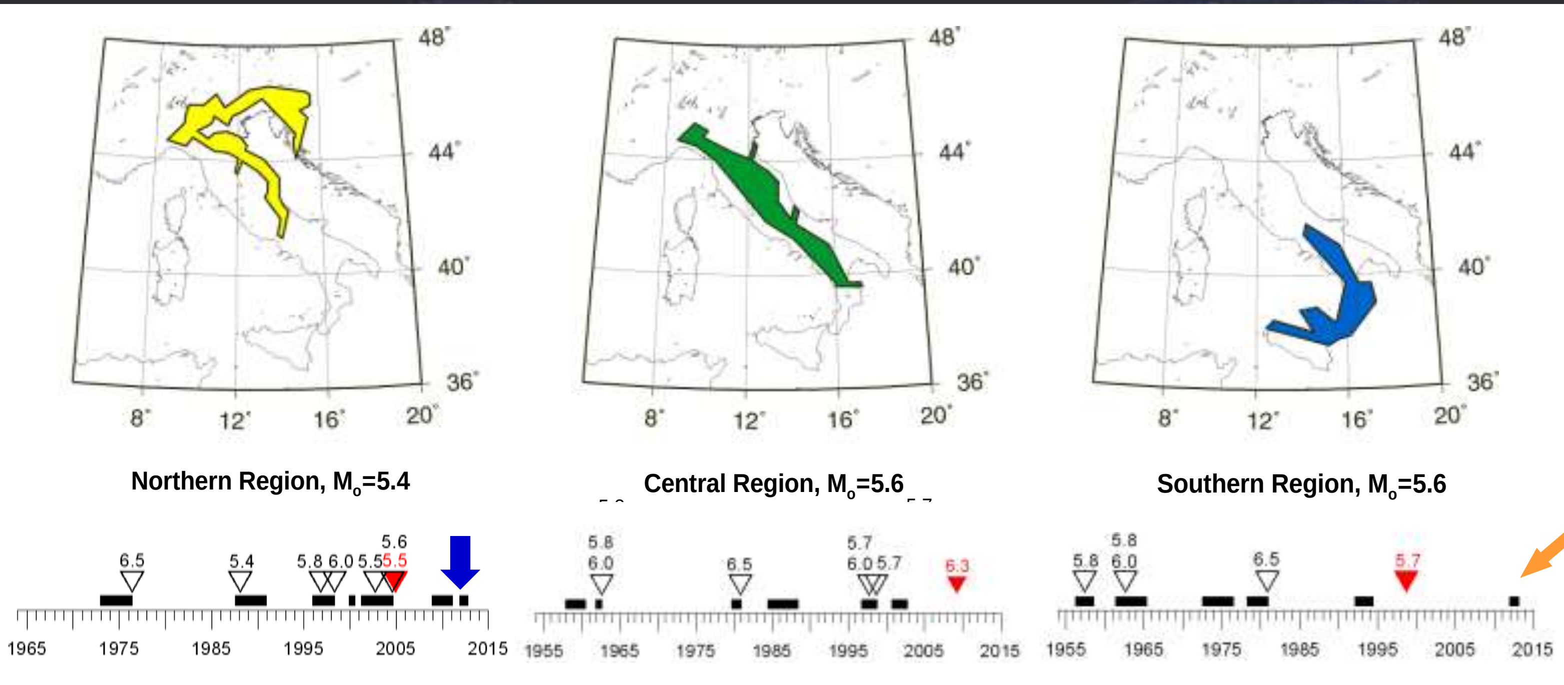
Confidence level tells how sure one can be that the achieved performance is not arisen by chance

V. Kossobokov (2012)
Earthquake prediction: 20 years of global experiment
Nat Hazards DOI 10.1007/s11069-012-0198-1

Intermediate-term middle-range earthquake prediction experiment in Italy

CN algorithm

Times of Increased Probability for the occurrence of events with M>Mo within the monitored regions



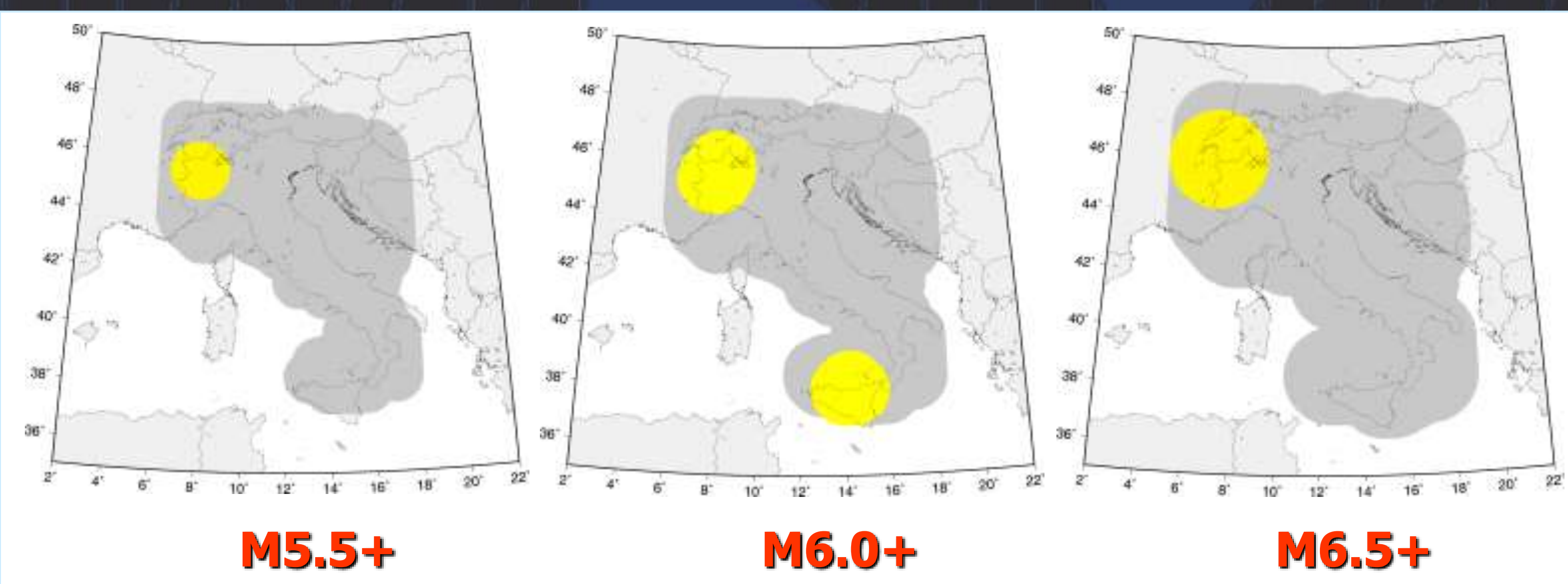
M8S algorithm

Monitored region

Alerted region

M_0+ corresponds to the magnitude range

$M_0 \leq M < M_0+0.5$

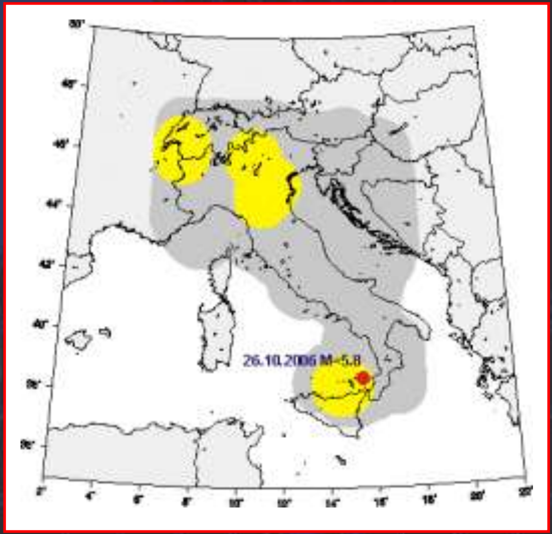


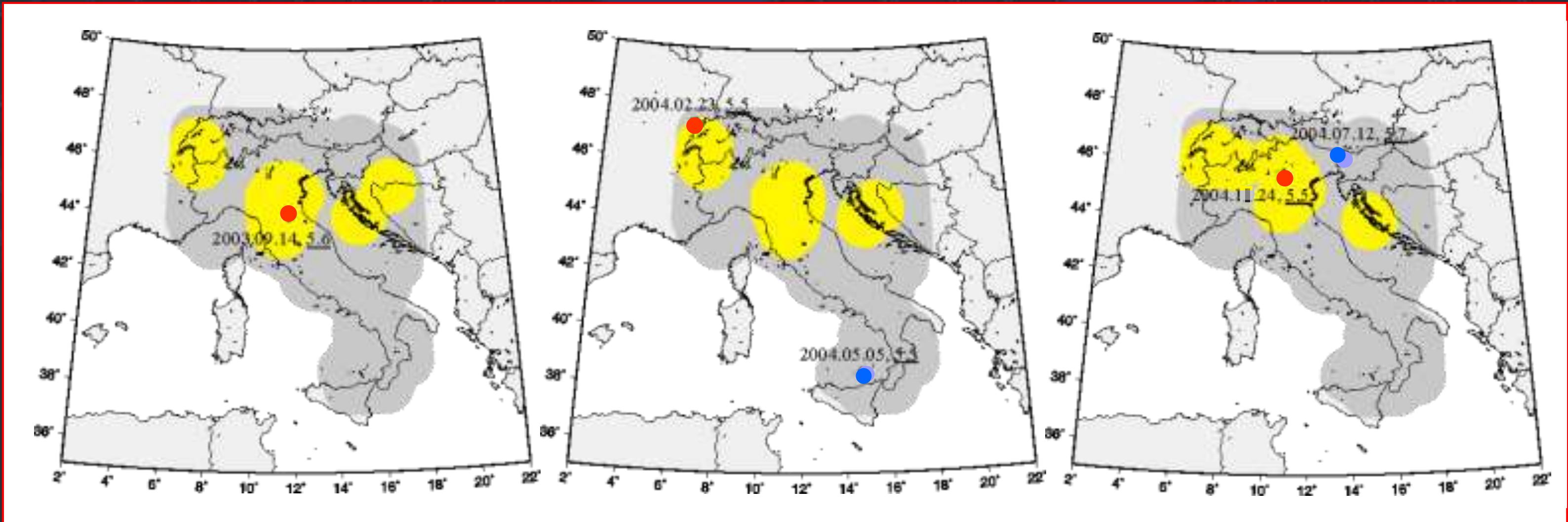
(*Peresan al., Earth Sci. Rev. 2005*)

The M8S real-time monitoring of seismic flow

Real-time testing M5.5+, 2002-2013

Date	Latitude, ⁰N	Longitude, ⁰E	Depth, км	M_{max}	M8S	Location
2002.09.06	38.38	13.70	5	5.9	No	Near Sicily
2002.10.31	41.79	14.87	10	5.9	No	South Italy
2003.03.29	43.11	15.46	10	5.5	Yes	Adriatic sea
2003.09.14	44.33	11.45	10	5.6	Yes	Near Bologna
2004.02.23	47.27	6.27	17	5.5	Yes	Switzerland
2004.05.05	38.51	14.82	228	5.5	No	Near Sicily
2004.07.12	46.30	13.64	24	5.6	No	Slovenia
2004.11.24	45.63	10.57	24	5.5	Yes	North Italy
2006.10.26	38.67	15.40	216	5.8	Yes	Near Sicily





Monitored region

Alerted region

Events with $M_{max} \geq 5.5$ occurred since July 2003

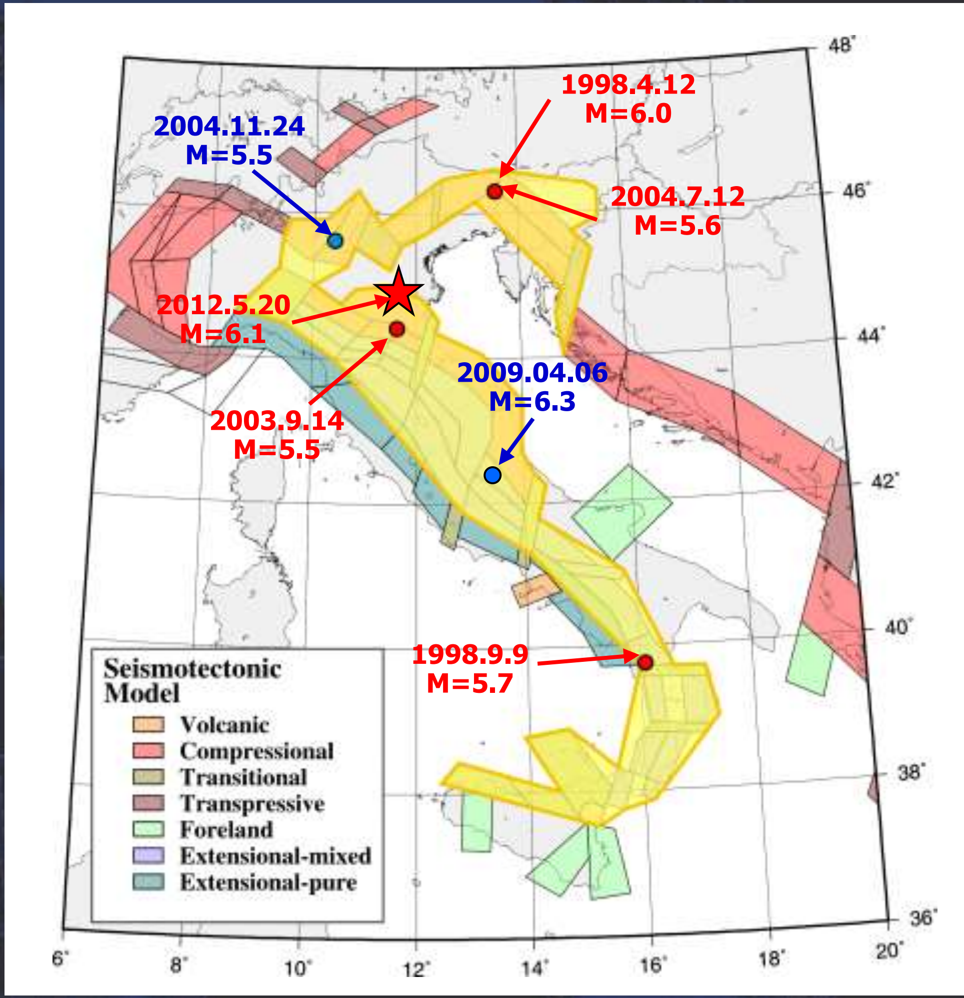
Updated to January 1 2013

The CN real-time monitoring of seismic flow

Real-time testing 1998-2011

Earthquakes occurred within the space-time-magnitude volume monitored by CN since 1998

Date	Latitude, ^{0}N	Longitude, ^{0}E	Depth, км	M	CN	Location
1998.04.12	46.24	13.65	10	6.0	Yes	Slovenia
1998.09.09	40.03	15.98	10	5.7	Yes	South Italy
2003.09.14	44.33	11.45	10	5.5	Yes	Near Bologna
2004.07.12	46.30	13.64	24	5.6	Yes	Slovenia
2004.11.24	45.63	10.57	24	5.5	No	North Italy
2009.04.06	42.33	13.33	9	6.3	No	Central Italy
2012.05.20	44.90	11.23	8	6.1	Yes	North Italy



Updated to January 1 2013 (next updating March 1 2013)

Intermediate-term middle-range earthquake prediction

Space-time volume of alarm in M8S application in Italy

Experiment	M6.5+		M6.0+		M5.5+	
	Space-time volume, %	n/N	Space-time volume, %	n/N	Space-time volume, %	n/N
Retrospective (1972-2001)	35	2/2	39	1/2	38	9/14
Forward (2002-2013)	24	0/0	31	0/2	14	5/9
All together (1972-2013)	32	2/2	37	1/4	31	14/23

Algorithm M8s predicted 60% of the events occurred in the monitored zones in Italy, i.e. 17 out of 29 events occurred within the area alerted for the corresponding magnitude range. The confidence level of M5.5+ predictions since 2002 has been estimated to be above 99%; no estimation is yet possible for other magnitude levels.

(updated to July 1 2013;
Next updating January 2014)

A complete archive of M8S predictions in Italy can be viewed at:
http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm
http://www.mitp.ru/prediction.htm

e-mail: lina@mitp.ru

Intermediate-term middle-range earthquake prediction

Space-time volume of alarm in CN application in Italy

Experiment	Space-time volume of alarm (%)	n/N	Confidence level (%)
Retrospective* (1954 – 1963)	41	3/3	93
Retrospective (1964 – 1997)	27	5/5	>99
Forward (1998 – 2013)	26	5/7	>98
All together (1954 – 2013)	29	13/15	>99

* Central and Southern regions only

Algorithm CN predicted 13 out of the 15 strong earthquakes occurred in the monitored zones of Italy, with less than 30% of the considered space-time volume occupied by alarms.

(updated to September 1 2013;
Next updating November 2013)

A complete archive of CN predictions in Italy can be viewed at:
http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm

e-mail: aperesan@units.it

Evaluation of prediction results

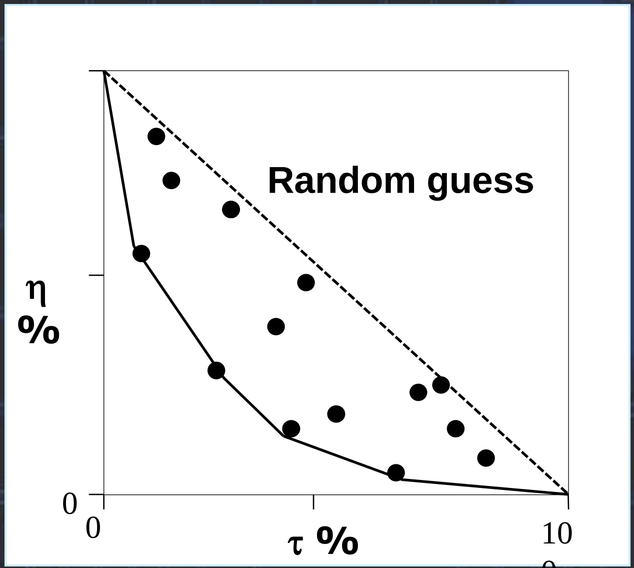
Intermediate-term middle-range earthquake prediction

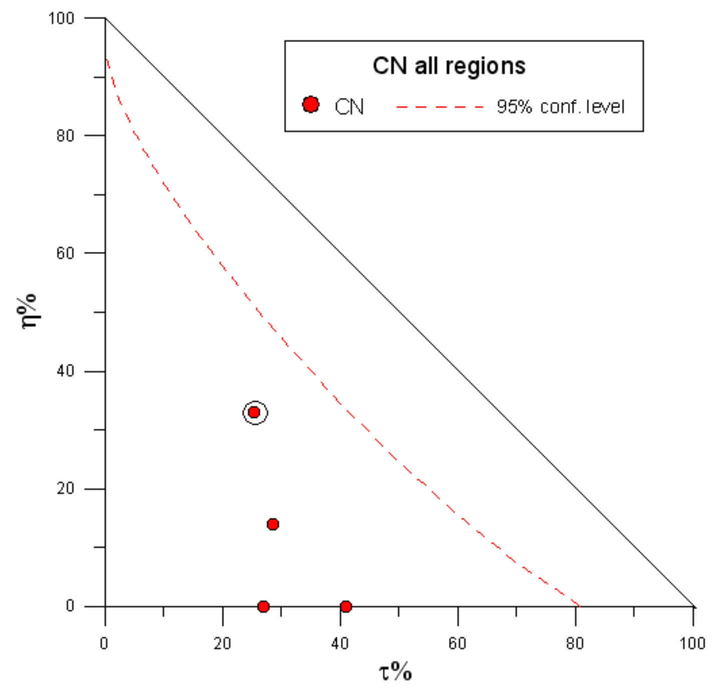
Evaluation of prediction results

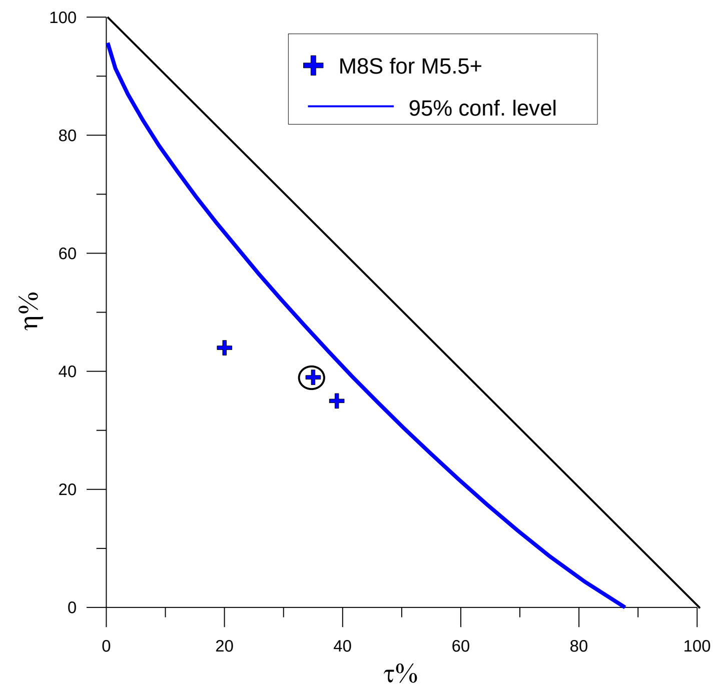
The quality of prediction results can be characterised by using two prediction parameters (*Molchan, 1997*) **:**

η : the rate of failures-to-predict (*n/N*)

τ : the space-time volume of alarm







CN and M8S predictions in Italy

Updated to March 1 2013 (next updating May 1 2013)

Intermediate-term middle-range earthquake prediction

Evaluation of results

CN prediction results for the Italian territory

		N events	Time (years)	Time %	Yearly probability %	GAIN
NORTH	All time	8	47,86	100	17	2,88
	Alarm	7	14,34	30	49	
	No Alarm	1	33,54	70	3	
CENTRE	All time	7	57,84	100	12	4,23
	Alarm time	6	11,73	20	51	
	No Alarm	1	46,11	80	2	
SOUTH	All time	5	57,92	100	9	3,18
	Alarm time	4	14,56	25	27	
	No Alarm	1	43,36	75	2	

- The yearly probablity for a strong earthquake occurrence (target event) within a monitored CN region varies in the range from 9% to about 15% .
- Accounting for prediction results, i.e. considering only TIP intervals of time (Alarm time), such probability increases up to 27% and 50%. This provides an estimate of the probability increase associated with an alarm, routinely updated according to the prediction results.
- The probability for a strong earthquake to occur within non-alarmed periods (No alarm) is around 2-3%.

Intermediate-term middle-range earthquake predictions

Interpretation of results

M8S ALL	N events	SpaceTimeVolume	Relative frequency	GAIN
All STV	23	100,00	0,23	1,69
Alarm STV	14	36,00	0,39	
FORWARD predictions				
All STV	9	100,00	0,09	**3.97**
Alarm STV	5	14,00	0,36	

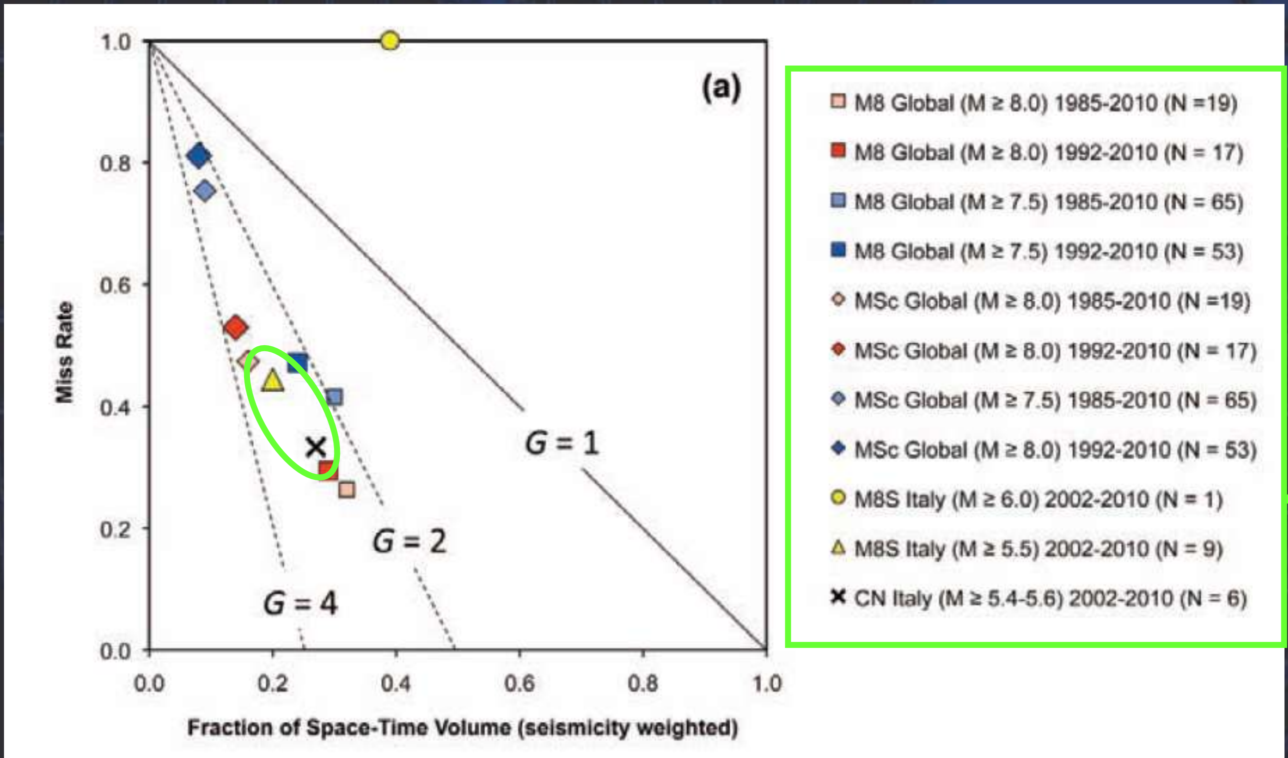
CN ALL	N events	SpaceTimeVolume	Relative frequency	GAIN
All STV	15	100,00	0,15	3,00
Alarm STV	13	28,70	0,45	
FORWARD predictions				
All STV	7	100,00	0,07	**2,80**
Alarm STV	5	25,48	0,19	

- Considering both retrospective and real-time predictions, the gain is higher for CN than for M8S predictions targeted to events with M5.5+.
- The probability gain attained in forward testing is higher for M8S predictions, due to the very low alarms rate.

Evaluation of prediction results: the ICEF report

Conclusions about M8 and CN algorithms performances:

"When an adequate sample of target earthquakes is available ($N > 10$), **these prediction methods show skill that is statistically significant** with respect to time-independent forecasts constructed by extrapolating spatially smoothed, catalog-derived earthquake rates to larger magnitudes. "



M8 and CN are already validated by rigorous real-time prediction results

T. Jordan et al. (Annals of Geophys, 54, 4, 2011; doi: 10.4401/ag-5350)

Evaluation of prediction results: CSEP Testing in Italy

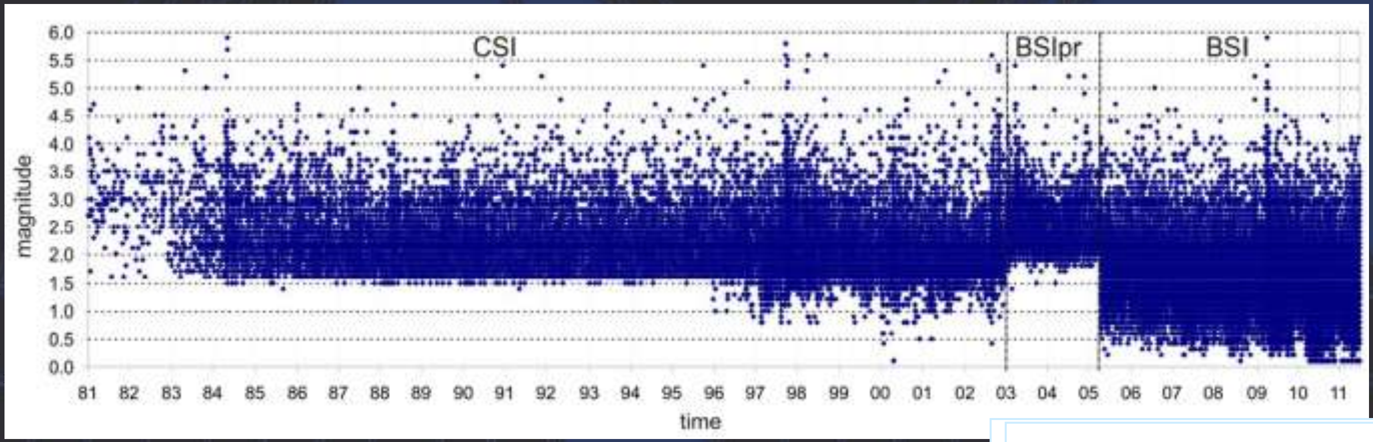
The Collaboratory for the Study of Earthquake Predictability (CSEP) aims to provide a well controlled environment in which earthquake forecasts can be run and evaluated.

The Italian testing region: Rules of the Game and some basic shortcomings

1. **Errors in the input data.** *"Models will be evaluated against the authoritative observed data supplied by INGV [...]. The INGV ML magnitude scale will be considered the reference scale for model development and testing."*
2. **Missing methods/criteria to compare** different alarm-based models and to compare alarm-based models with probability-based models.
3. **Short testing time interval:** five years testing could be too short to reach any conclusion about the effectiveness of predictions for the largest earthquakes.
4. **Non real-time predictions.** *"Tests are performed with a delay of 30 days relative to real-time, in order for the authoritative data to be manually revised and published."*
5. **Independency** amongst testing centers, data providers and modelists should be guaranteed

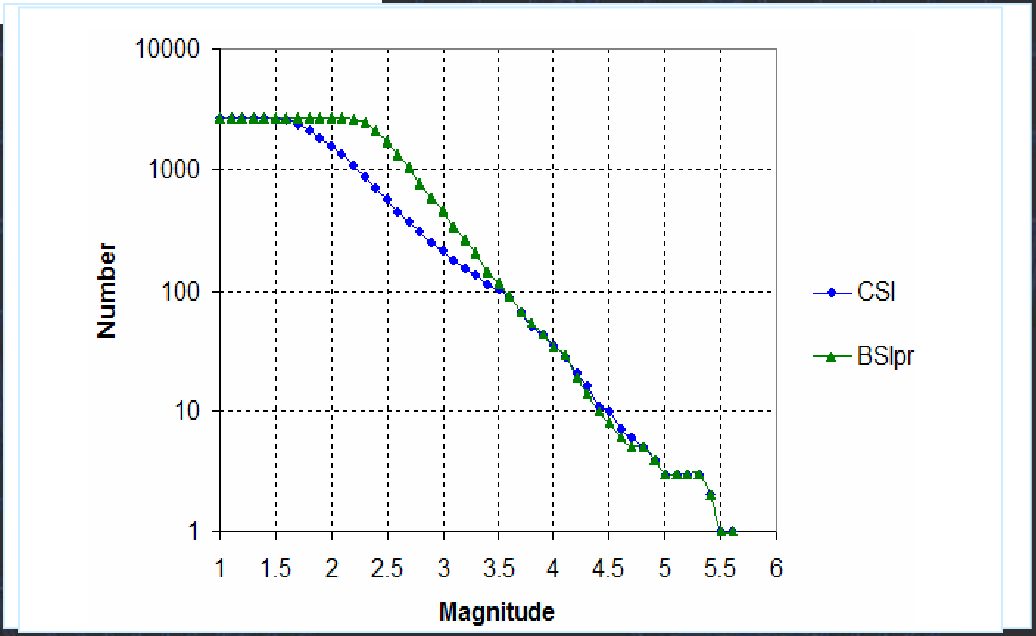
(http://www.cseptesting.org/regions/italy/models),

Earthquake catalogs for CSEP testing in Italy



Italy

Dot-plot showing the magnitude versus origin time for the earthquakes reported in Italian instrumental catalogs used for CSEP-TRI

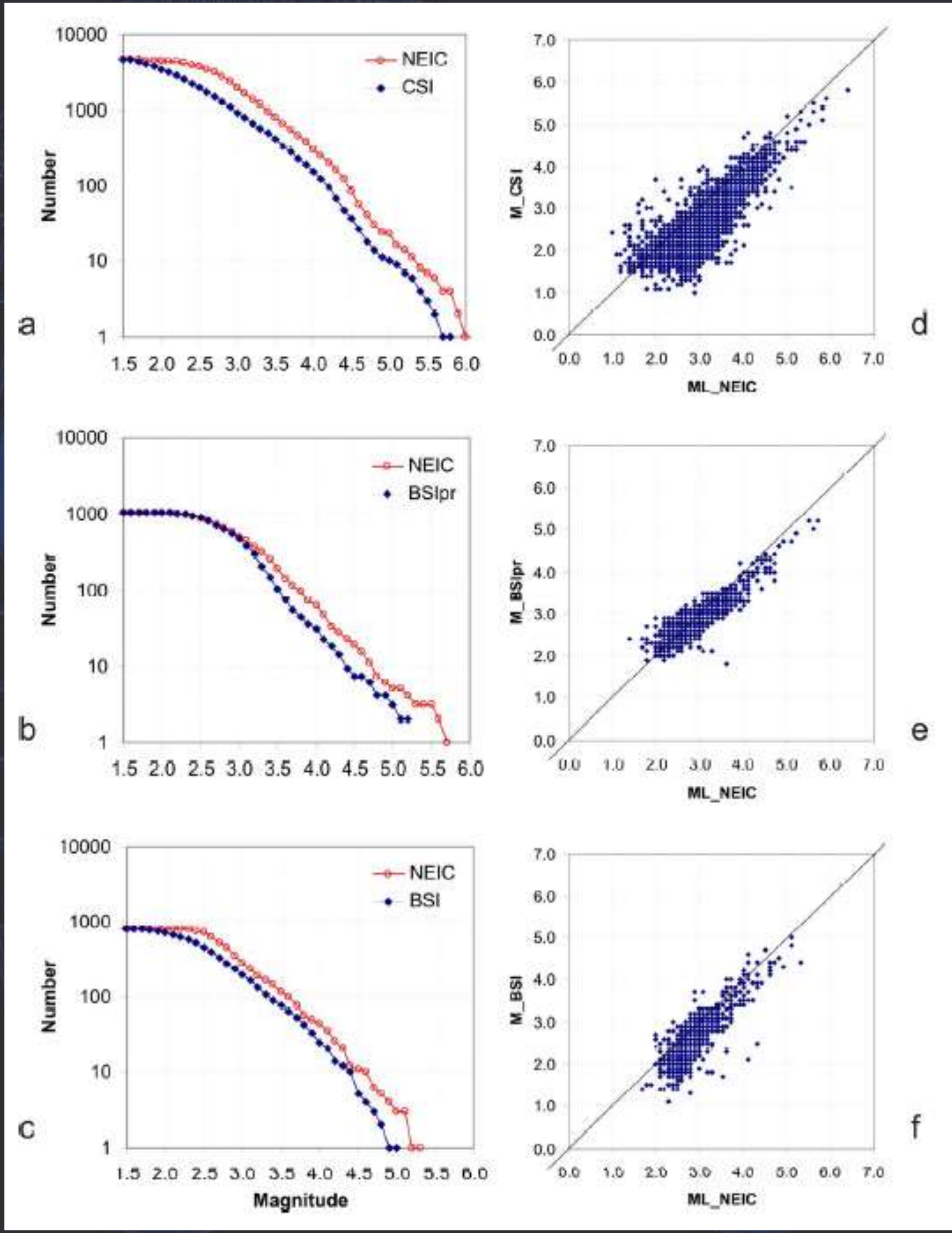


Annual frequency-magnitude distributions and likelihood estimates of b-value as a function of MC for three datasets: CSI1.1 – from 1985 through 2002; BSIpr – from 2003 to 15 April 2005; and BSI – since April 2005

Romashkova, L., Peresan, A. (2012). Analysis of Italian earthquake catalogs in the context of intermediate-term prediction problem, Acta Geophysica, DOI: 10.2478/s11600-012-0085-x

Earthquake catalogs for CSEP testing in Italy

M_{max}



Frequency-magnitude distributions and *M*_CSEP *versus M*_NEIC plots for equivalent earthquakes in the global and Italian catalogs

Earthquake catalogs for CSEP testing in Italy

5. Data

According to the "rules of the game", the testing center has provided modelers with three catalogs for forecast-model development: two historical catalogs, known as the CPTI (Catalogo Parametrico dei Terremoti Italiani; http://emidius.mi.ingv.it/CPTI/), from 1901 to 2006, and the CSI 1.1 (Catalogo della Sismicità Italiana; http://csi.rm.ingv.it/), from 1981 to 2002; plus the Italian seismic bulletin (Bollettino Sismico Italiano, BSI; http://bollettinosismico.rm.ingv.it/) that currently provides data since April 16, 2005. The bulletin data prior to this date are still being revised. The testing center provides modelers with the BSI that include data until March 31, 2009, for model development and forecast generation. That is, we cannot use data from April 1, 2009, to the model submission deadline (June 31, 2009).

For our model development, we used the CSI 1.1 and the BSI because the magnitude scale used for these catalogs is the local magnitude scale and both include the microseismicity data. On the other hand, the CPTI includes macroseismicity. Furthermore, each event cataloged in CPTI has information on the magnitude in one or multiple scales: the scales used are body-wave magnitude, moment magnitude, surface magnitude, and local magnitude. There is no obvious authorized conversion equation between the local magnitude scale and the moment magnitude scale for Italy, and we would like to use microearthquake information to construct RI forecasts. Thus, we did not use the CPTI.

We also did not use CSI 1.1 data prior to 1985, because the number of reported earthquakes in the period of 1981-1984 was quite small. This was associated with the many network changes that occurred in the early 1980s.

The gap between the periods over which the CSI 1.1 and the BSI cover ranges from t_{GS} = January 1, 2003, to t_{GE} = April 15, 2005. In our forecast generation, the effect of this gap is taken into consideration where there is the need to use the two catalogs for the generation.

Kazuyoshi Z. Nanjo (2010). *"Earthquake forecast models for Italy based on the RI algorithm"*. ANNALS OF GEOPHYSICS, 53, 3, 2010; doi: 10.4401/ag-4810

Earthquake catalogs for CSEP testing in Italy

Bulletin of the Seismological Society of America, Vol. 103, No. 4, pp. 2227–2246, August 2013, doi: 10.1785/0120120356

Empirical Calibration of Local Magnitude Data Sets Versus Moment Magnitude in Italy

by Paolo Gasperini, Barbara Lolli, and Gianfranco Vannucci

For CSI M_L, the 107 data points with an M_w in the IMW data set (Fig. 8) do not show a significant scaling disagreement but only a significant average offset of 0.24 ± 0.02. It is not easy to explain such average underestimation of CSI M_w with respect to M_w as it can be supposed that the CSI compilers used the standard WA amplification factor $A_0 = 2800$ to compute SWA waveforms (unfortunately, the point is not mentioned in the paper by Castello *et al.*,

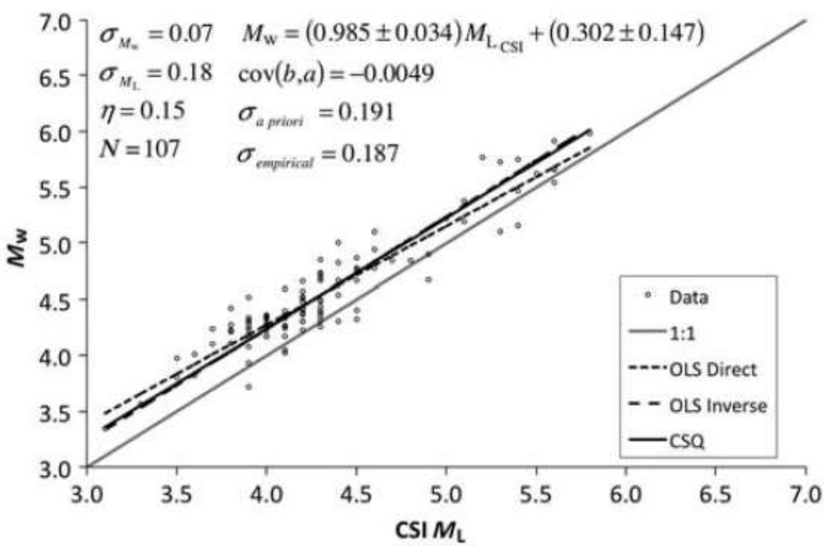


Figure 8. Same as Figure 4 for M_w versus CSI M_L with resized uncertainties.

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error procedure based on *a priori* information and regression results.

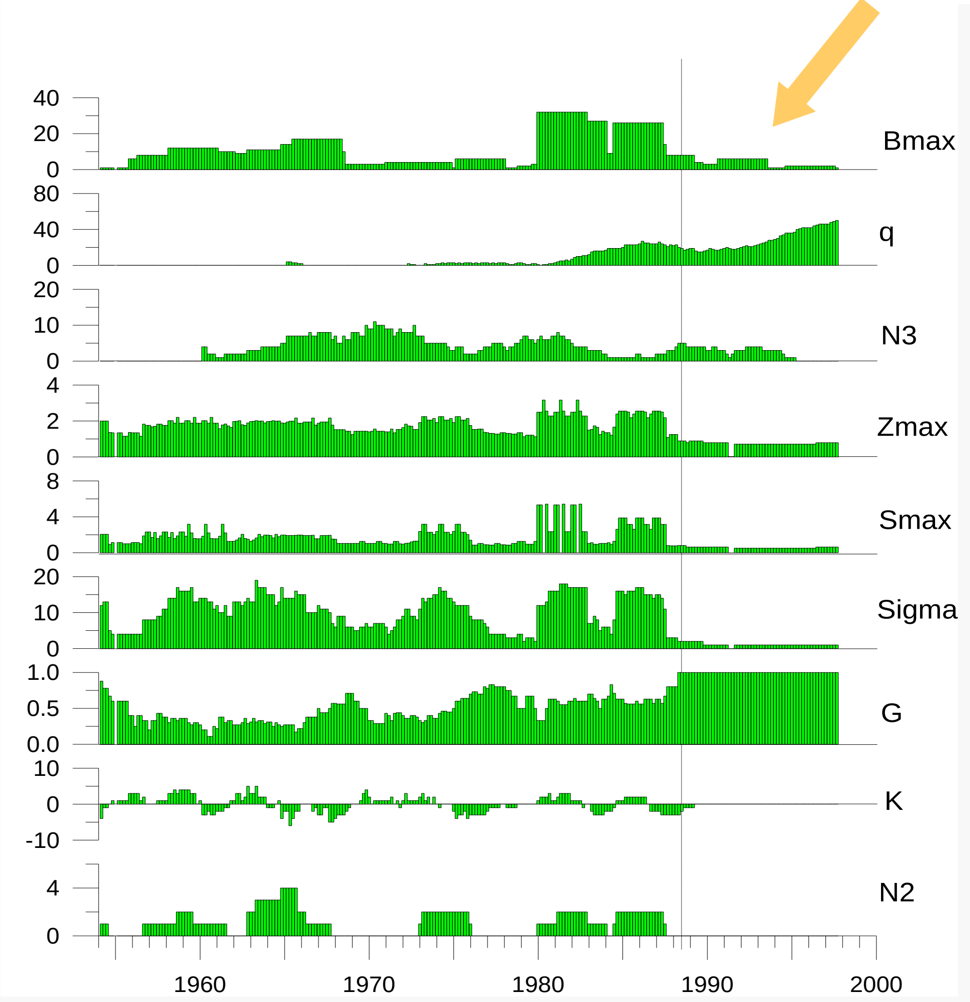
M_L estimates computed from real or simulated Wood–Anderson waveforms scale 1:1 with respect to M_w, with the only exception being the ISIDE online bulletin, but are generally underestimated with respect to M_w. Therefore, to convert to M_w the M_L, estimates from CSTI, CSI, and BSI data sets needs only a positive shift of 0.15, 0.23, and 0.08 units, respectively.

We suggest that the scaling bias of ISIDE M_L might be

CSEP testing in Italy: errors in the input data

Existing heterogeneities in the input catalog may significantly affect any related characterization of seismicity and thus the detection of premonitory patterns

Time diagrams of the standard CN functions in the Central region ***(Peresan et al., 1999)***



Effect of local magnitude underestimation on the standard CN functions

Evaluation of prediction results: CSEP Testing in Italy

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On the Testing of Seismicity Models

George MOLCHAN

[1]International Institute of Earthquake Prediction Theory
and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russia
e-mail: molchan@mitp.ru

[2]The Abdus Salam International Centre for Theoretical Physics,
SAND Group, Trieste, Italy

Abstract

Recently a likelihood-based methodology has been developed by the Collaboratory for the Study of Earthquake Predictability (CSEP) with a view to testing and ranking seismicity models. We analyze this approach from the standpoint of possible applications to hazard analysis. We arrive at the conclusion that model testing can be made more efficient by focusing on some integral characteristics of the seismicity distribution. This can be achieved either in the likelihood framework but with economical and physically reasonable coarsening of the phase space or by choosing a suitable measure of closeness between empirical and model seismicity rate in this space.

7. CONCLUSIONS

The CSEP experiment deals with testing and ranking of seismicity rate models. In this approach there is no prior limitation on the number of models, all models are a priori equally acceptable, and the number of partition elements of phase space, n, to group the data is large. Under these conditions the advantage of the likelihood (LH) method that is used as the main tool is not obvious.

We analyzed theoretically the LH method in two particular cases: (i) numbers of events $\{v_j\}$ in space bins are large, which can be of interest for testing the long-term seismicity maps, and (ii) the $\{v_j\}$ are small, which is typical of the CSEP experiments. In the second case, LH method loses a highly desirable property, namely, statistical consistency. In other words, there exist nontrivial models which cannot be classified as wrong by the LH method as the number of observations N becomes large. The same is true regarding the other tests being used under the less stringent limitations on $\{v_j\}$ (the R and the Area Skill Score tests).

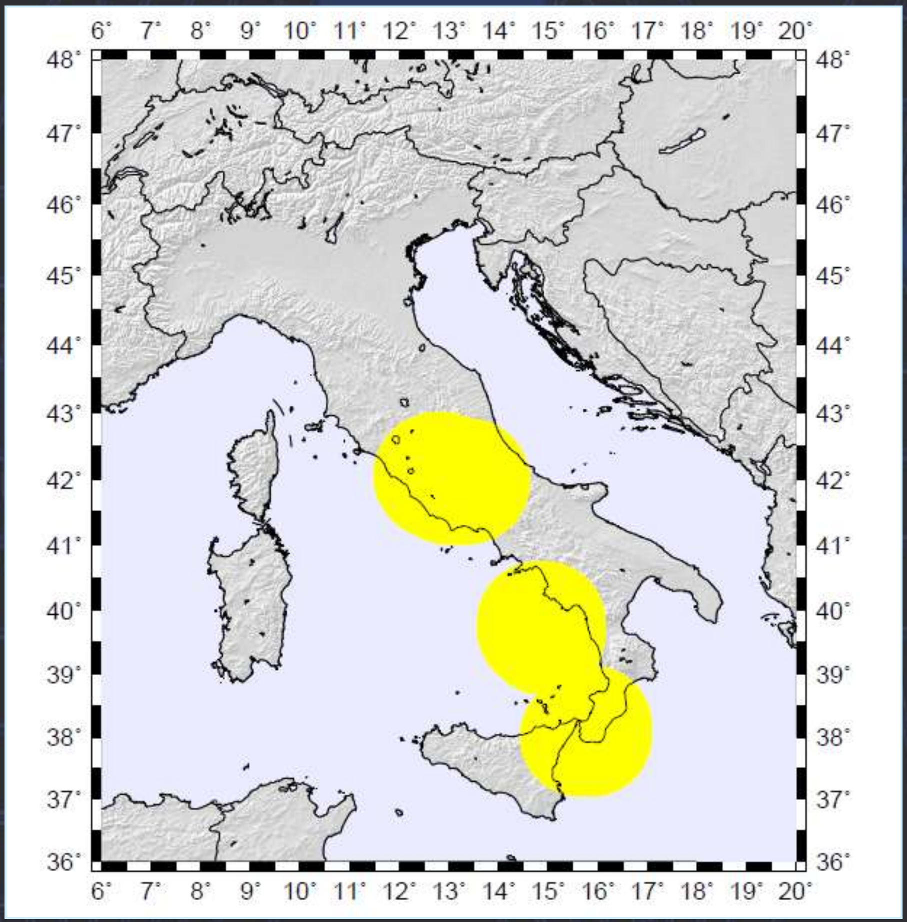
The case of small $\{v_j\}$ arises from the detailed partition of the phase space, *i.e.*, when n is large. As a result, an additional undesirable property of the test methodology appears. The testing procedure is based on the rate model and on the assumption of independence of the variables $\{v_j\}$. Selection of the correct rate model is the most important part of the testing while the independence property is usually questionable. The greater n is, the more the independence property affects on the statistical conclusions. Consequently the statistical test analysis should be as weakly sensitive to this property as

NDSHA Time-dependent Scenarios of Ground Shaking

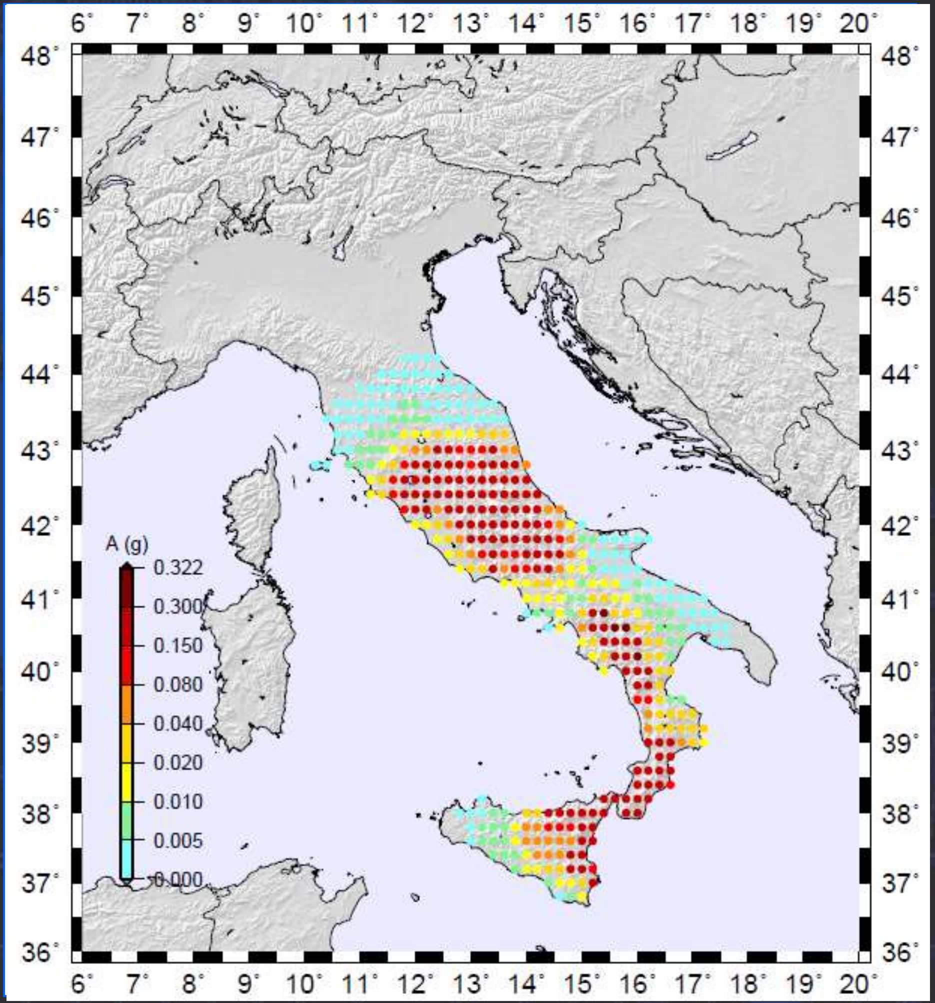
Regional ground shaking scenarios associated with alerted regions

(ground motion at bedrock)

Time-dependent Scenarios of Ground Shaking
(associated with alerted regions)



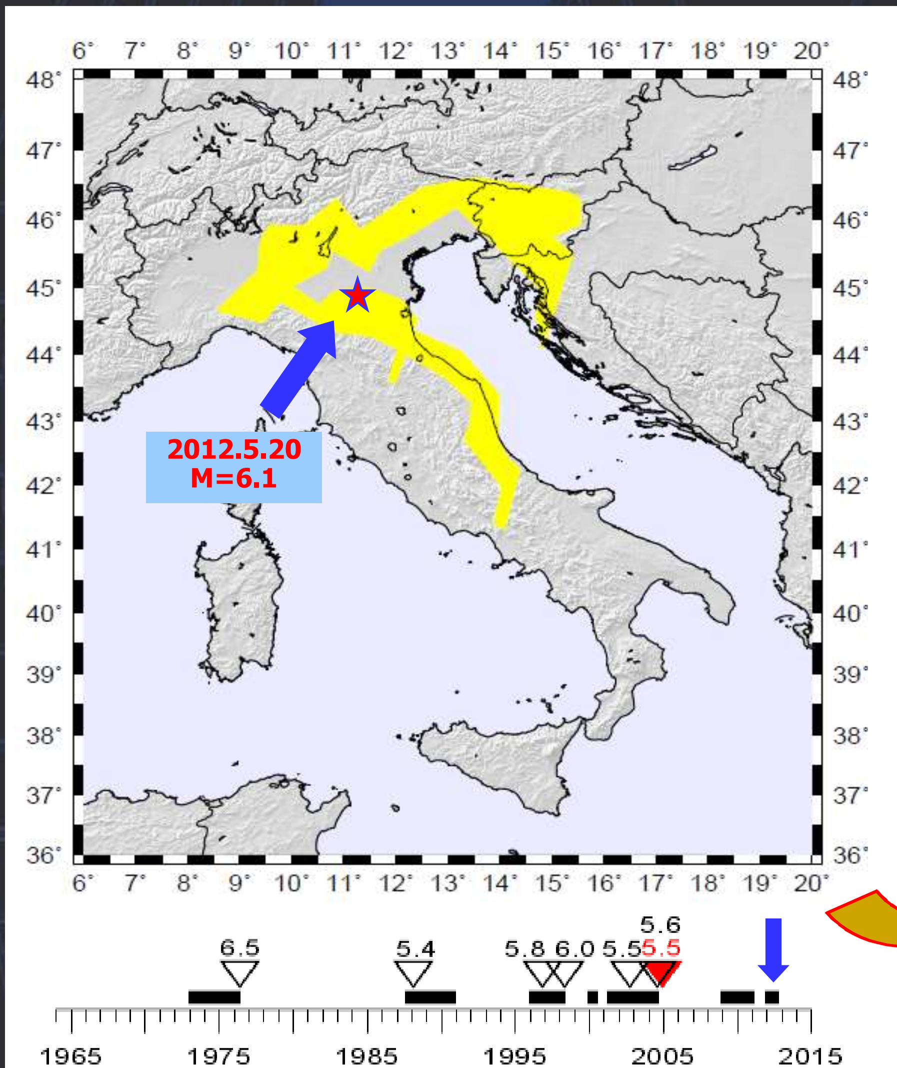
Region alerted by algorithm M8S for a possible earthquake with M5.5+

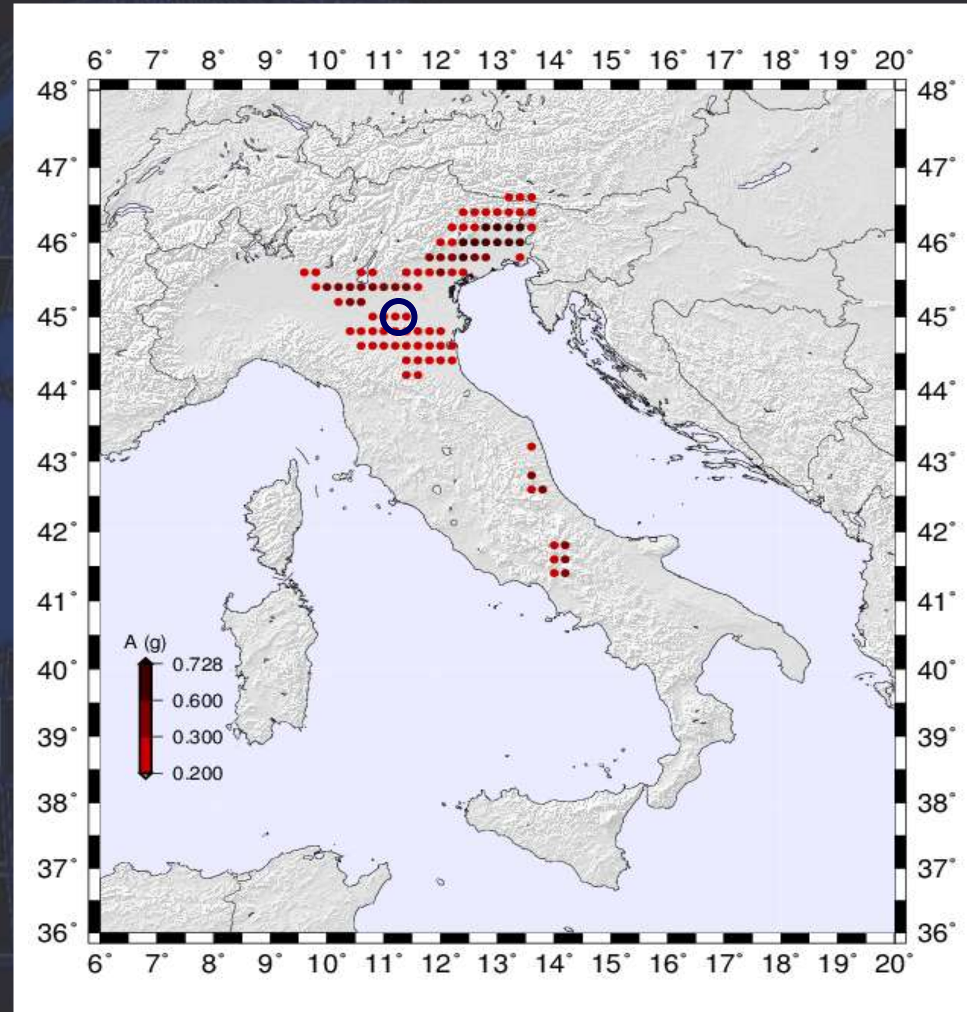


The Ground-shaking scenarios associated to the alerted regions are regularly updated every six months according to the issued alerts

Max frequency: 10 Hz
Max source-receiver distance: 150 km

The Emilia earthquake 20th May 2012

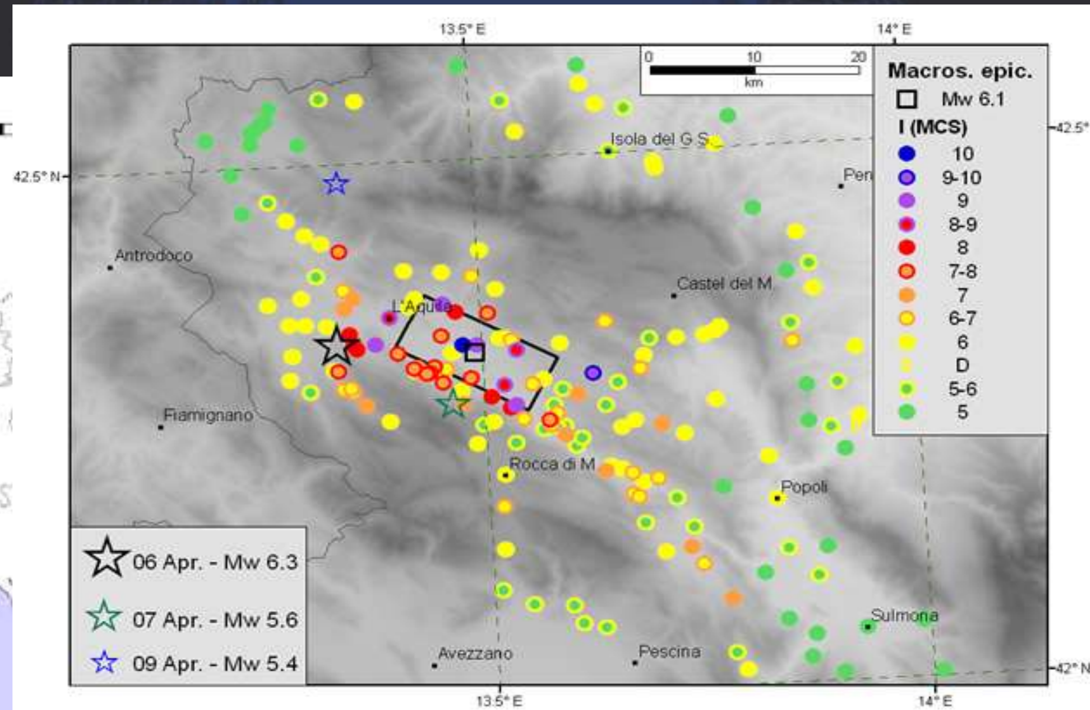




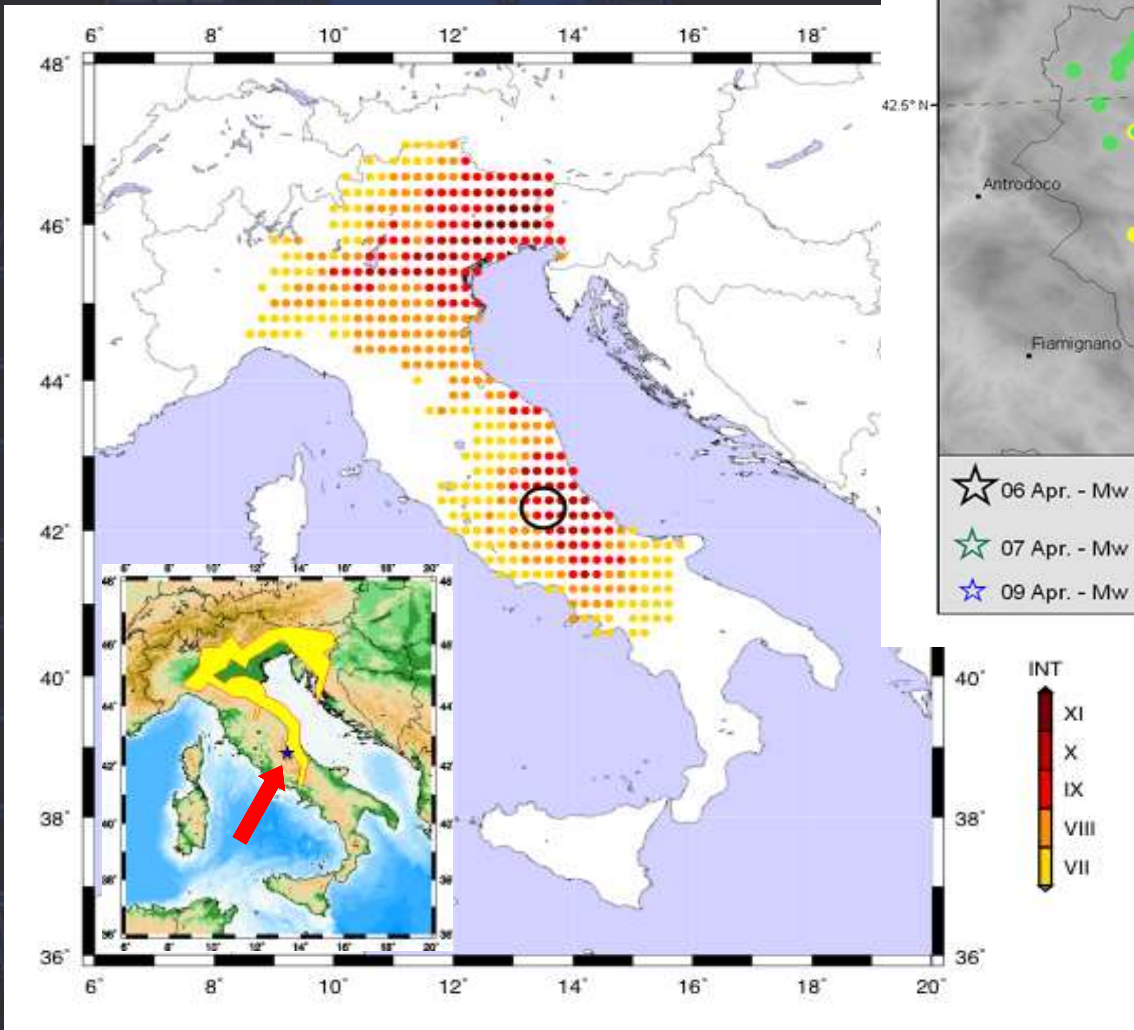
Time-dependent ground-shaking scenario associated with CN Northern Region, as defined for the period 1 May – 30 June 2012

Northern Region (yellow) monitored by **CN algorithm** for an earthquake with **M≥5.4**

The Aquilano M6.3 earthquake, 6th April 2009



QEST-Rapporto sugli effetti del terremoto aquilano del 6 aprile 2009 [RPT03 – 20.04.2009]



Scenario of MCS intensity associated with the alarmed area, as defined for the period 1 March 2009 – 1 May 2009. The epicenter is indicated by the circle

Although the epicenter was about 10 km outside the alarmed CN territory (failure to predict) ⇒The time dependent scenario of ground motion correctly predicted the occurred Intensities

Local scale scenarios

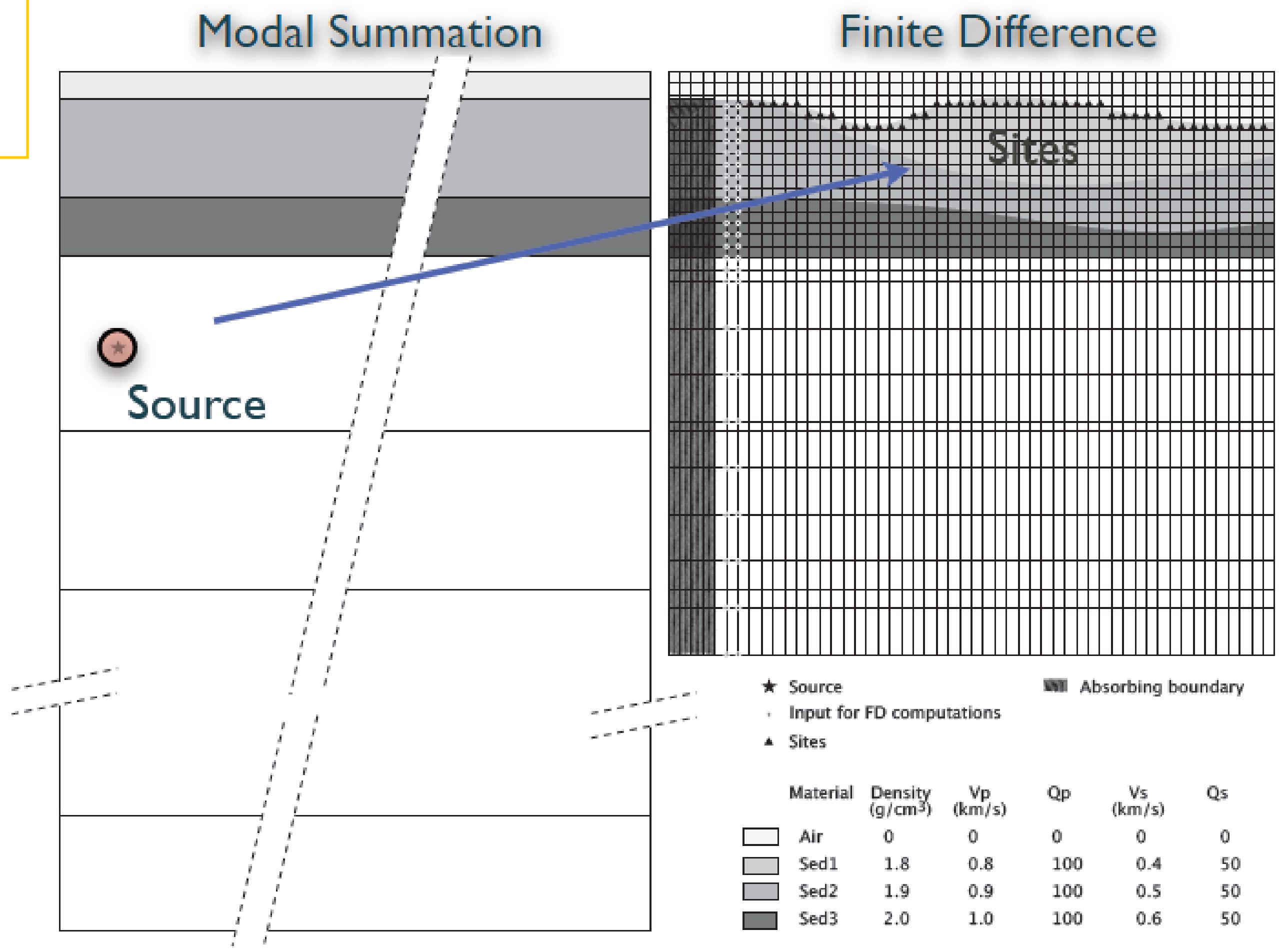
including 2D lateral heterogeneities and local soil conditions

Hybrid Method:
Modal Summation
+ Finite Differences

1D layered anelastic structure

+

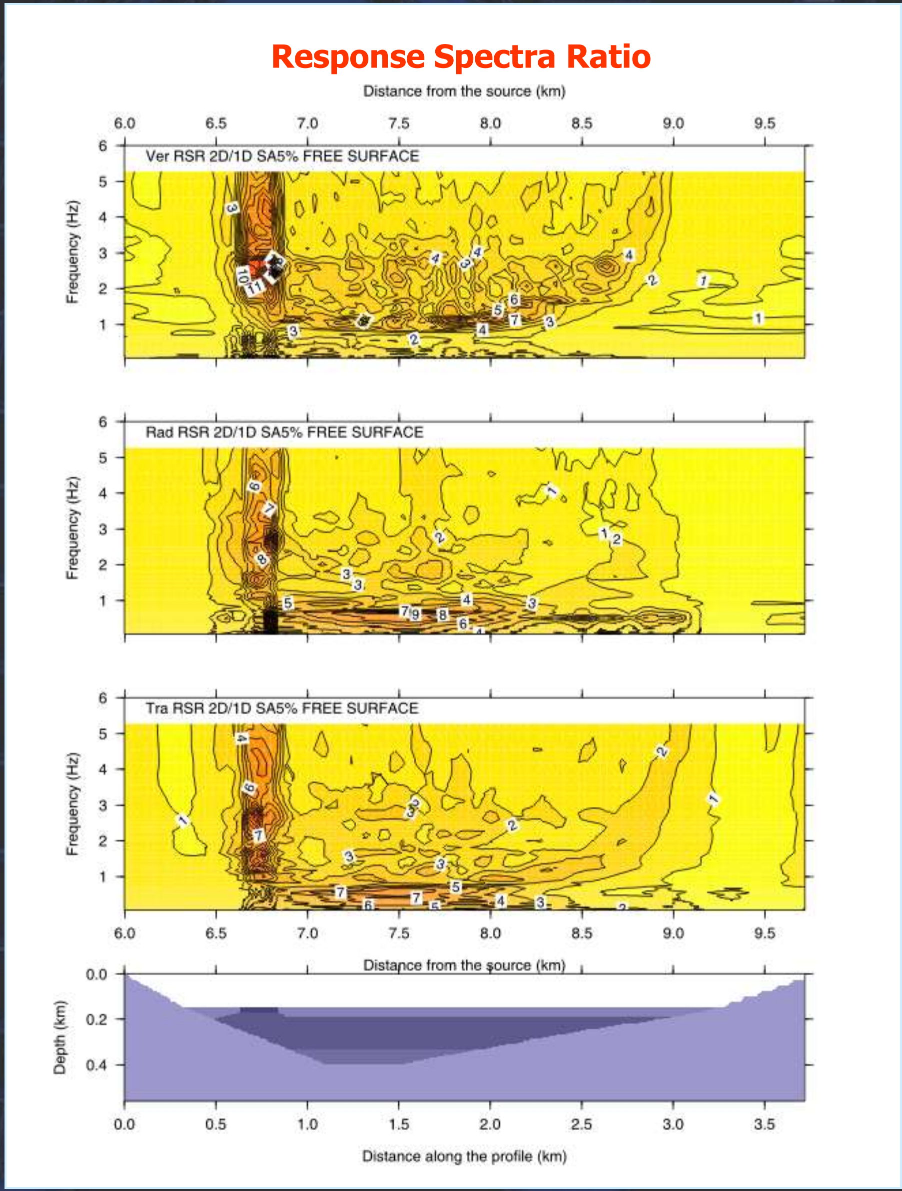
2D laterally heterogeneous local structure

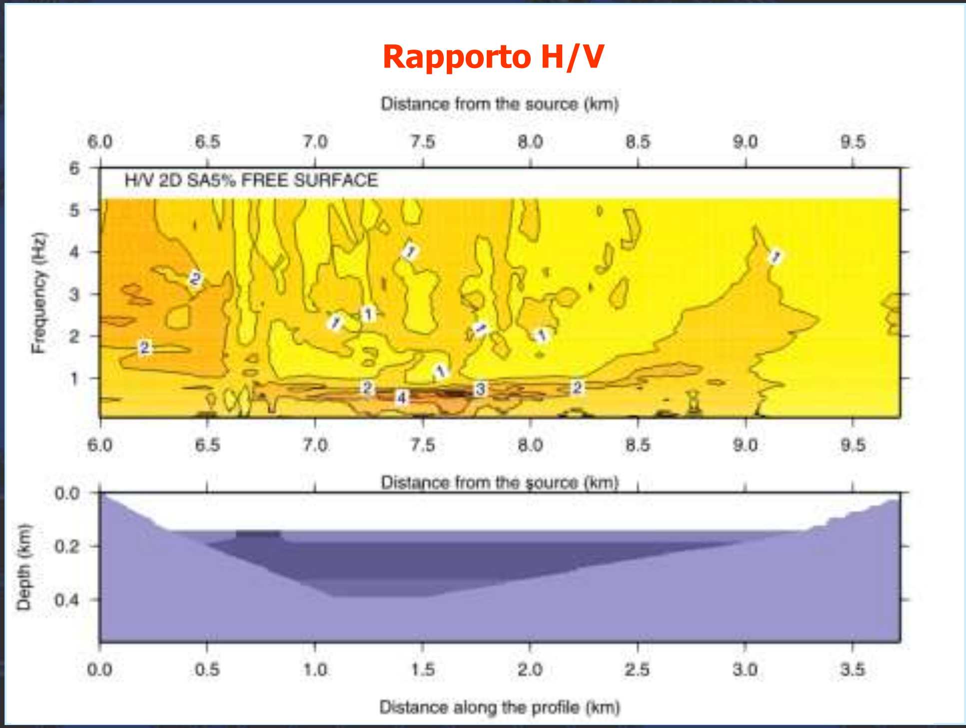


	Material	Density (g/cm³)	Vp (km/s)	Qp	Vs (km/s)	Qs
	Air	0	0	0	0	0
	Sed1	1.8	0.8	100	0.4	50
	Sed2	1.9	0.9	100	0.5	50
	Sed3	2.0	1.0	100	0.6	50

Detailed scenario of ground motion including local site effects

Example: scenarios of ground motion in the city of L'Aquila





The ratio H/V, based on the same synthetic seismograms, does not allow to evidentiate the relevant amplifications associated with low velocity sediments (Aterno river).

2D Model from *De Luca et al. (2005). BSSA, 95, 1469–1481*

F. Vaccari, vaccari@units.it

Integrating information from different observables

ASI Pilot Project - SISMA

"Seismic Information System for Monitoring and Alert"

Development of a fully formalized system for the time dependent neo-deterministic definition of seismic hazard, integrating the space and time information provided by real-time monitoring of seismic flow and Earth Observation (GNSS, SAR) data analysis, through geophysical forward modeling.

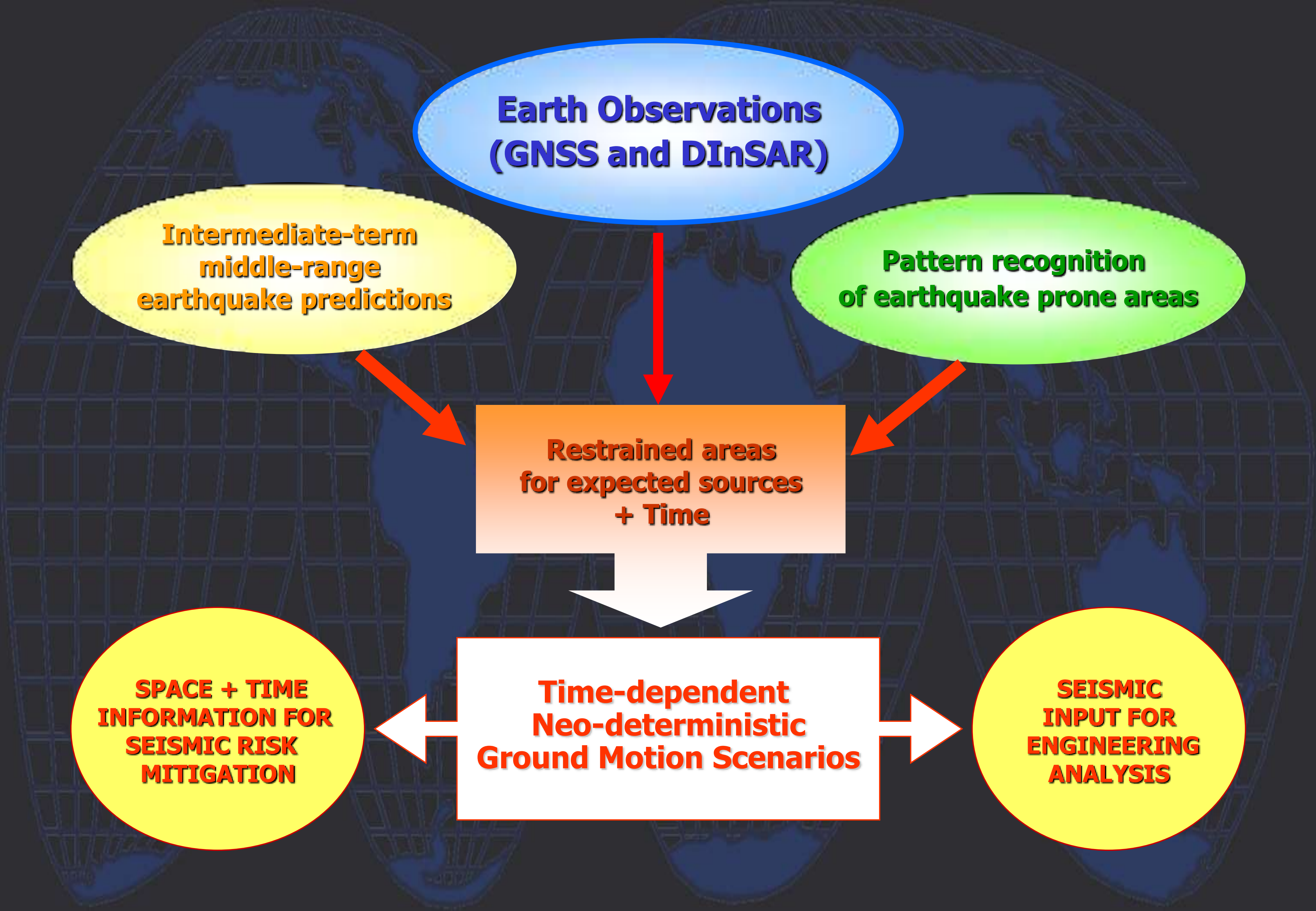
agenzia spaziale italiana

DST

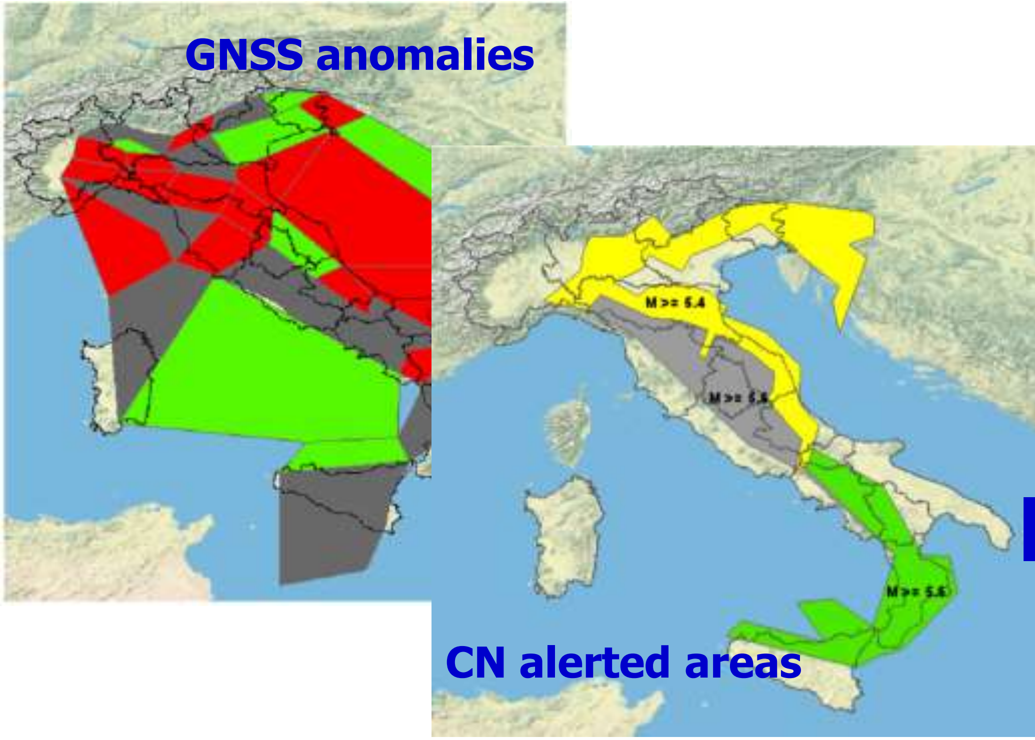
University of Milano

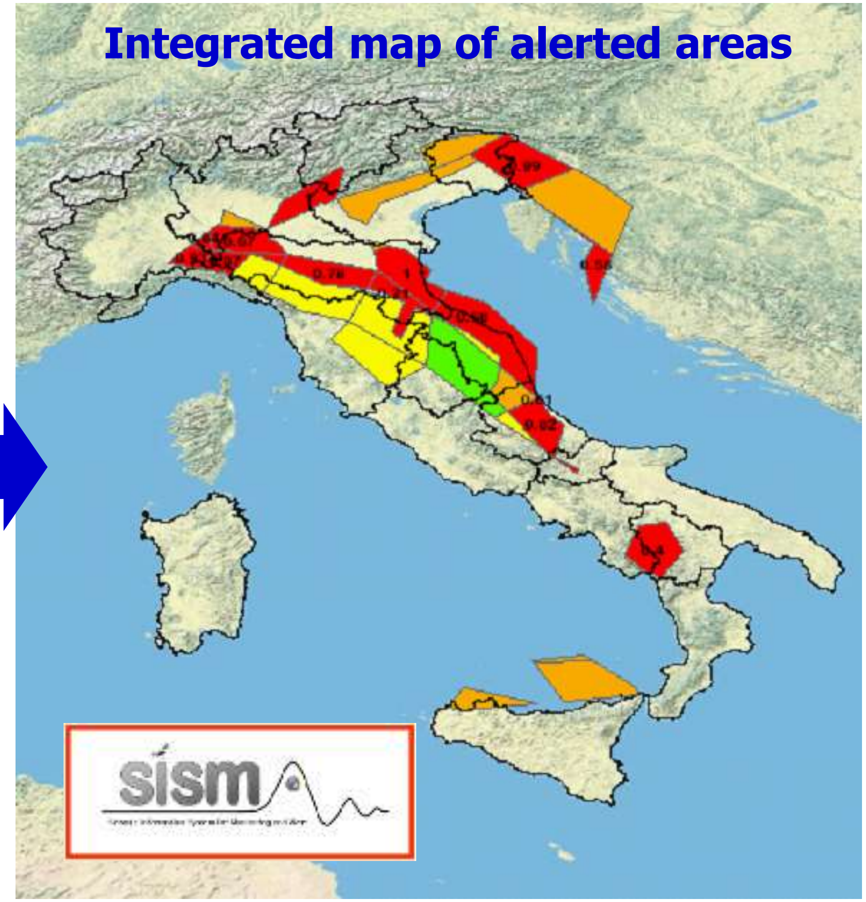
Politecnico di Milano

galileian PLUS


Earth Observations
(GNSS and DInSAR)
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
Time-dependent
Neo-deterministic
Ground Motion Scenarios
SEISMIC
INPUT FOR
ENGINEERING
ANALYSIS

Toward integration with Earth-Observation data





- **First fully formalized system for the joint analysis of strain field and seismic stress release**
- **Well controlled prospective testing and validation of the proposed methodologies over the Italian territory.**
- **Operational GIS interface: maps routinely updated and delivered to the Civil Defence every two months**

(*Panza et al., Nat. Haz. 2011*)

http://sisma.galileianplus.it/

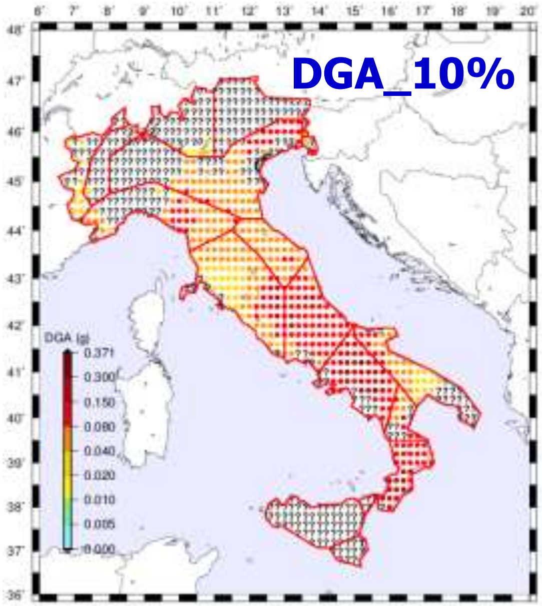
Comparing ground shaking from models and intensities from past earthquakes

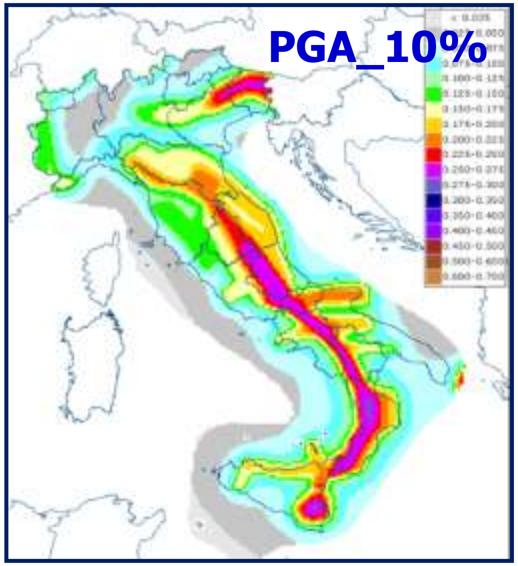
Seismic hazard assessment

- Rigorous and objective testing of seismic hazard assessments against the real seismic activity is a necessary precondition for any responsible seismic risk estimation.

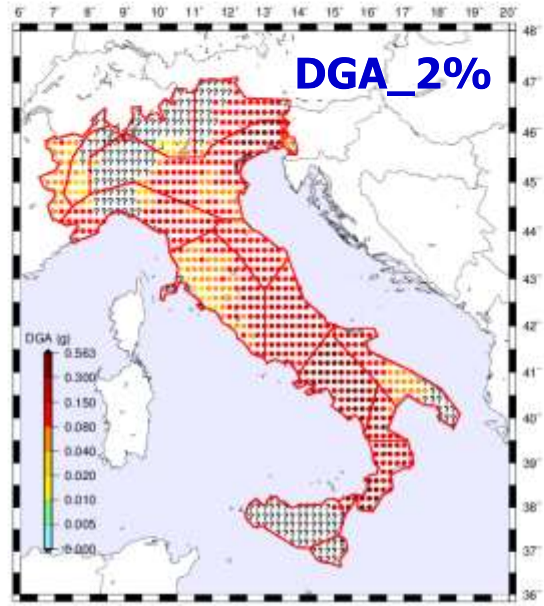
- Seismic hazard maps seek to predict the shaking that would actually occur ⇒ the reference hazard maps for the Italian seismic code, obtained by PSHA, and alternative ground shaking maps based on NDSHA and USLE, are cross-compared and tested against the real seismicity for the territory of Italy.

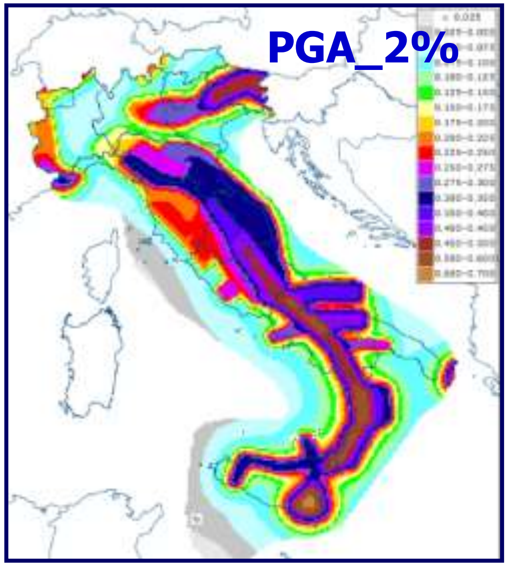
Seismic hazard maps of Italy



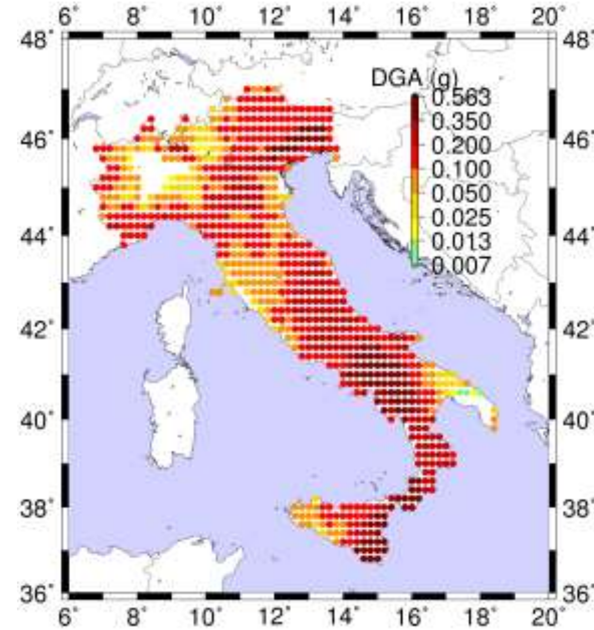


Return Period T = 475 years

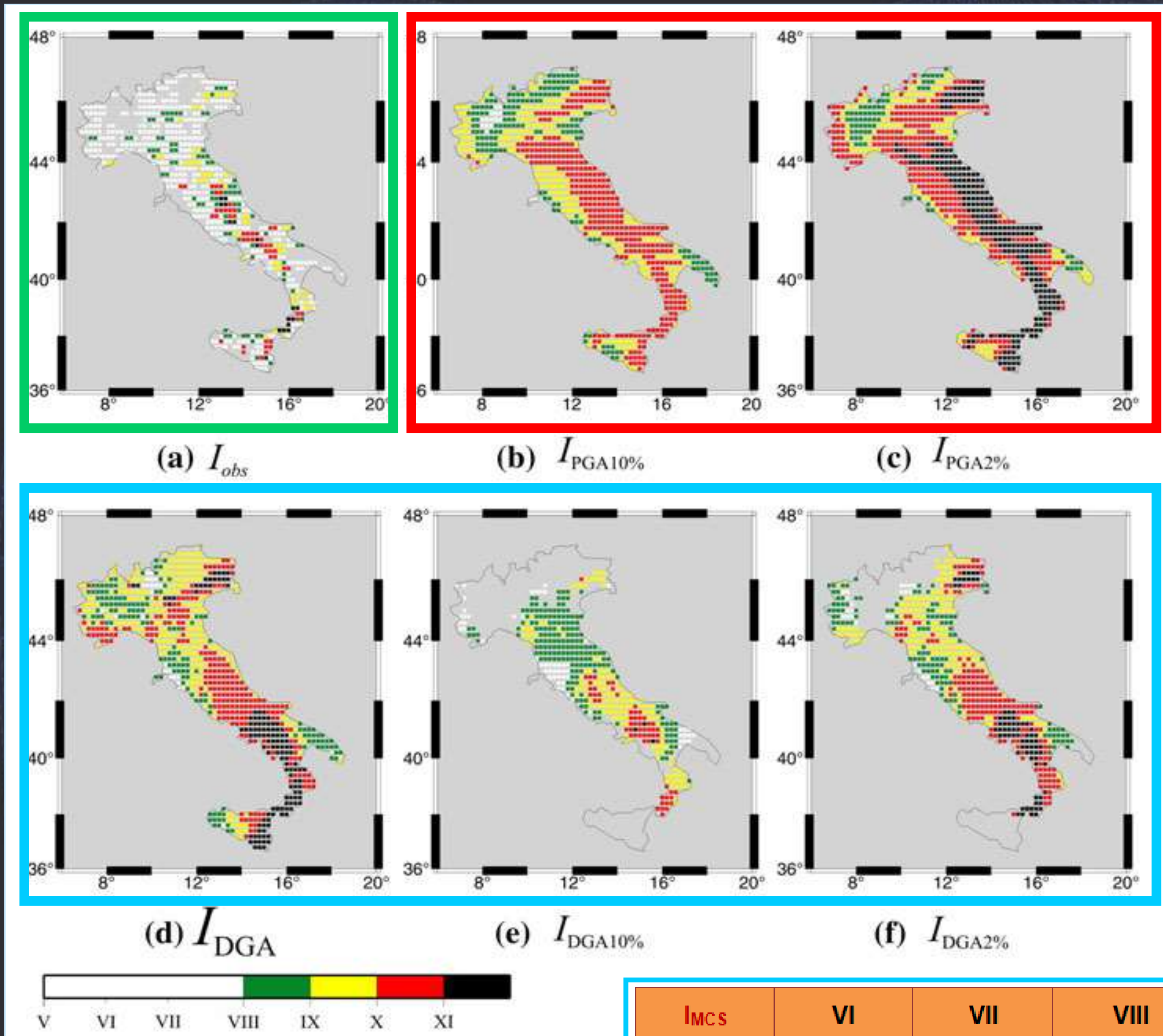




Return period T = 2475 years



NDSHA Standard



Observed seismicity vs PSHA and NDSHA seismic hazard maps of Italy

Maximum ground shaking is expressed in terms of expected intensities I_{MCS}

- Model Ground Accelerations, mGA (g) with probability of exceedance of 10% and 2% in 50 years (return period 475 and 2475 years) are considered. http://zonesismiche.mi.ingv.it/

- I_{obs} is obtained from the real seismicity, CPTI04 catalog

I_{MCS}	VI	VII	VIII	IX	X	XI
mGA, (g)	0.01-0.02	0.02-0.04	0.04 – 0.08	0.08 – 0.15	0.15-0.3	0.3-0.6

Indirli et al (2011), Pageoph, vol. 168c

Comparing expected and observed intensities

Percentage of I_{MCS} from different ranges in the six intensity maps

$P(I_{MCS})$, %						
I_{MCS}	Observation	PGA10%	PGA2%	DGA	DGA10%	DGA2%
≥ XI	3.01	-	33.75	15.75	0.67	12.37
≥X	11.70	43.88	73.50	45.88	13.84	42.88
≥IX	23.05	76.25	90.63	78.38	45.09	73.73
≥VIII	37.77	97.88	100	96.88	87.05	95.42

All model maps assign intensity VIII or larger for more than 90% the territory of investigation (about 600 grid points), whereas the I_{obs} map of intensities just for 38% (based on more than one thousand years observations).

Nekrasova, Kossobokov, Peresan, Magrin (2013), Nat. Hazards

Verification against large past earthquakes

Binomial test of the hazard maps and macroseismic observations:

maps are compared with location of seismic events with maximum intensity **I*obs* ≥ VIII** at epicenter – as reported in CPTI04 catalog and in DBMI04 macroseismic database

Statistical significance P: $P = 1 - B(N_{s+} - 1, N_s, N_{I+}/N_{all})$

- ✓ $B(m,n,p)$ is the binomial distribution function giving the probability of m or less successes on random in n trials, with probability p of success in a single trial
- ✓ N_{s+} and N_s are the numbers of the strong seismic events (I>VIII) in agreement with intensity map and total for the territory under investigation
- ✓ N_{all} is the total number of grid nodes of an intensity map
- ✓ N_{I+} is the number of the nodes with intensity I or more.

Verification against large past earthquakes

Binomial test of the hazard maps and macroseismic observations against earthquakes from the four intensity ranges

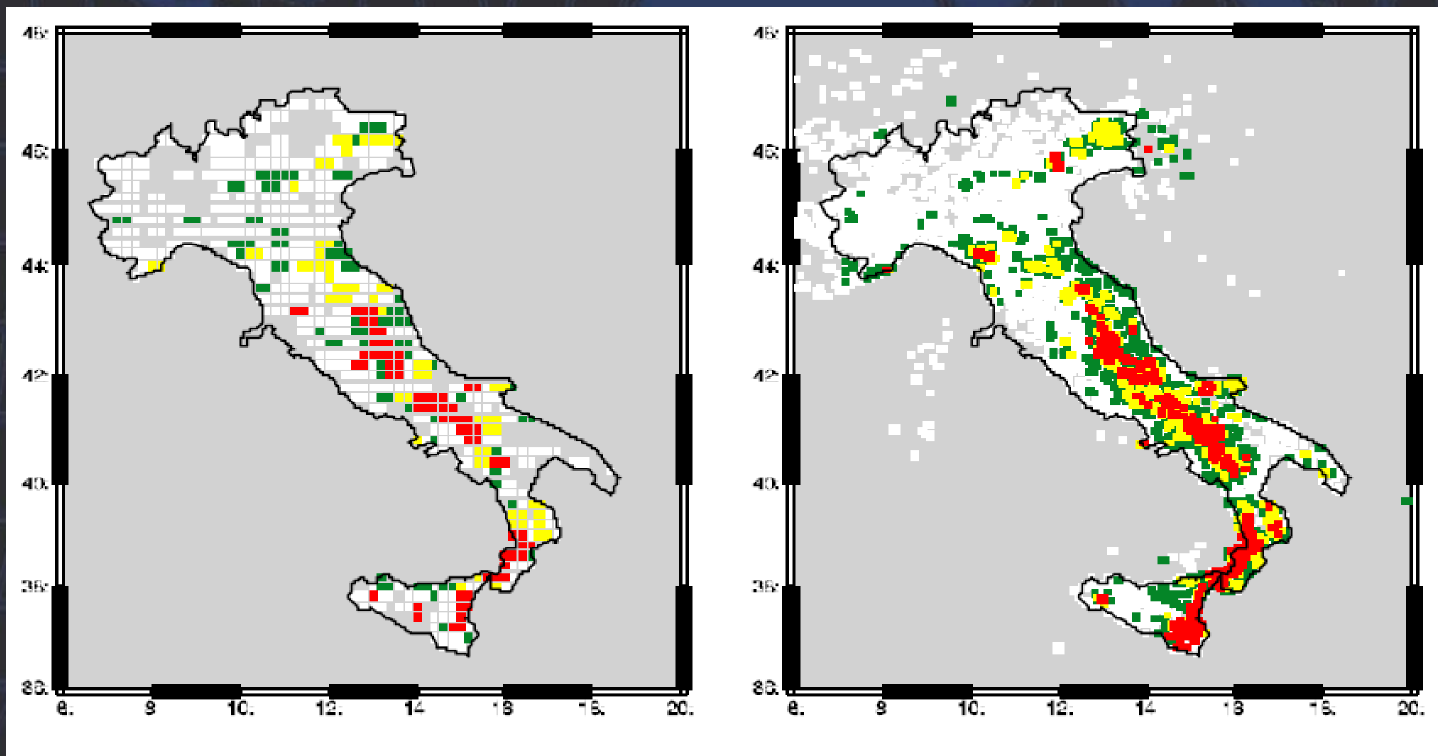
Map	VIII	IX	X	XI
PGA10%	99.84%	0.06%	0.28%	na
PGA2%	100.00%	0.05%	0.03%	0.02%
DGA	54.54%	0.00%	0.00%	0.03%
DGA10%	100.00%	1.31%	0.02%	na
DGA2%	29.54%	0.00%	0.04%	1.08%
DBMI04	0.00%	0.00%	0.00%	0.00%

Binomial probability P = $1\text{-}B(N_{s+} - 1, N_s, N_{I+}/N_{all})$

For the intensity range VIII the correspondence between reported intensities and all hazard maps can be attributed to a random coincidence, while it appears significant for higher intensities

Predictive capability of hazard maps

Earthquakes reported in CPTI04 catalogue and intensities reported in DBMI04 are compared with model maps, to check for "failures to predict" ***(Kossobokov & Nekrasova, 2011),*** **i.e. events exceeding the given estimates. The obtained results are qualitatively the same as for the global comparison, with PGA_10% missing the largest events.**

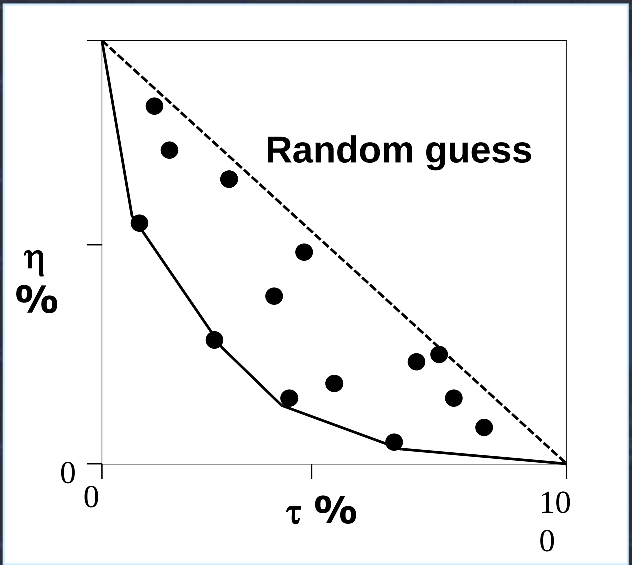


(a) I_{obs} (b) I DBMI04

Predictive capability of hazard maps

The quality of prediction results can be characterised by using two prediction parameters (*Molchan, 1997*) **:**

η : the rate of "failures to predict"
(events with $I_{obs}>I_{map}$)
τ : the rate of territory assigned intensity I or larger



$\eta + \tau$ =100%
Random guess

Number of DBMI04 intensities that exceed mGA-maps prediction

I	DBMI04	PGA10		PGA2		DGA	
	N_{I+}	N_{I+}	$\Delta I>0$	N_{I+}	$\Delta I>0$	N_{I+}	$\Delta I>0$
XI	65	-	65	270	0	126	8
X	535	351	201	588	2	367	27
IX	1572	610	206	725	3	627	50
VIII	4421	783	208	800	3	775	56

Sum of errors for the three model maps compared to DBMI04

I	PGA10%	PGA2%	DGA
XI	100.00	33.75	28.06
X	81.45	73.87	50.92
IX	89.35	90.82	81.56
VIII	102.58	100.07	98.14

Nekrasova, Kossobokov, Peresan, Magrin (2013), Nat. Hazards

Conclusions

- Fully formalized algorithms for intermediate-term middle range earthquake predictions are currently applied for the routine monitoring of Italian seismicity. The real-time monitoring of seismic flow allows for the rigorous prospective testing of CN and M8S predictions.

- The neo-deterministic NDSHA approach permits to account for earthquake recurrence, as well as for the space-time information provided by formally defined and tested earthquake predictions.

- The time-dependent NDSHA approach provides tools for establishing warning criteria and supplies decision makers an objective tool indicating priorities for timely mitigation actions (e.g. retrofitting of critical structures).

Conclusions

- Except for PGA10%, which underestimates the largest events, models generally provide rather conservative estimates, which tend to over-estimate the hazard particularly for the lower intensity events and yet do not guarantee avoiding the errors.
- PSHA maps have a higher tendency to over-estimate the hazard, with respect to other existing seismic hazard maps.
- NDSHA maps appear to outscore the PSHA ones in terms of efficiency in anticipating ground shaking, measured accounting for the rate of underestimated events.