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SISMA Project
National scale scenarios of ground shaking associated with alerted areas

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Advanced Conference on Seismic Risk Mitigation & Sustainable Development
10-14 May 2010, The Abdus Salam International Centre for Theoretical Physics
Miramare - Trieste

SISMA Project

National scale scenarios of ground shaking associated with alerted areas

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galileian PLUS *la forza del metodo*
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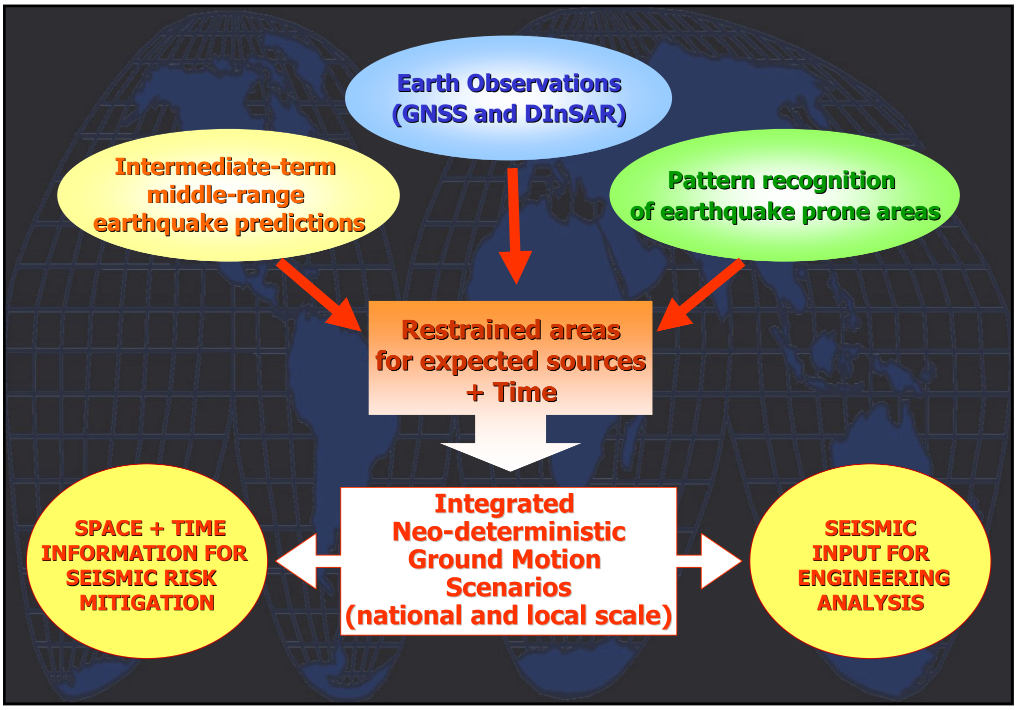
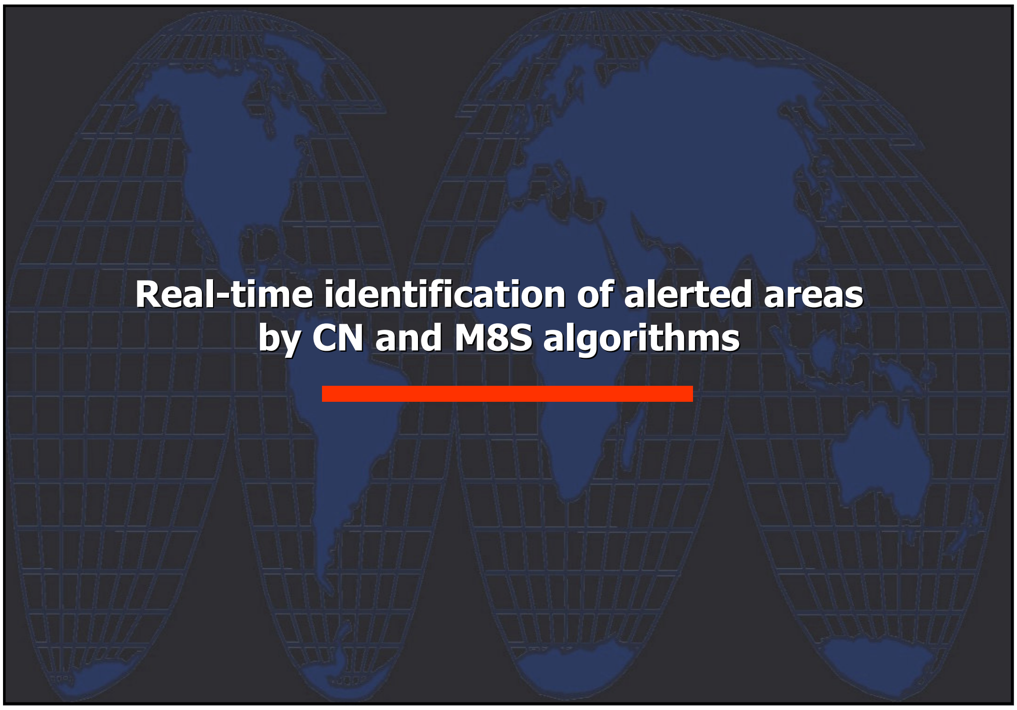
agenzia spaziale italiana

Outline

Integrated neo-deterministic seismic hazard assessment:

- Real-time identification of alerted areas by CN and M8S algorithms
- Testing and validation of earthquake predictions
- Pattern-recognition of earthquake prone areas
- Time-dependent ground shaking scenarios for alerted areas
- The L'Aquila earthquake


Earth Observations
(GNSS and DInSAR)
Intermediate-term
middle-range
earthquake predictions
Pattern recognition
of earthquake prone areas
Restrained areas
for expected sources
+ Time
Integrated
Neo-deterministic
Ground Motion
Scenarios
(national and local scale)
SPACE + TIME
INFORMATION FOR
SEISMIC RISK
MITIGATION
SEISMIC
INPUT FOR
ENGINEERING
ANALYSIS


Real-time identification of alerted areas
by CN and M8S algorithms

Real-time identification of alerted areas by CN and M8S algorithms

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

Real-time identification of alerted areas by CN and M8S algorithms

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

Main features:

- 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 15 years already permitted to assess the significance of the issued predictions.

Italy:

- Stability tests with respect to several free parameters of the algorithms *(e.g. Costa et al., 1995; Peresan et al., GJI, 2000; Peresan et al., PEPI, 130, 2002);*
- CN predictions are regularly updated every two months since January 1998.
- M8S predictions are regularly updated every six months since January 2002.

→ **Real time prospective testing started in July 2003**
(*Peresan al., Earth Sci. Rev. 2005*).

Intermediate-term middle-range earthquake prediction experiment in Italy

The prediction experiment, **ongoing for more than six years**, is aimed at a ***real-time test*** of CN and M8S predictions in Italy.

Updated predictions are regularly posted at:

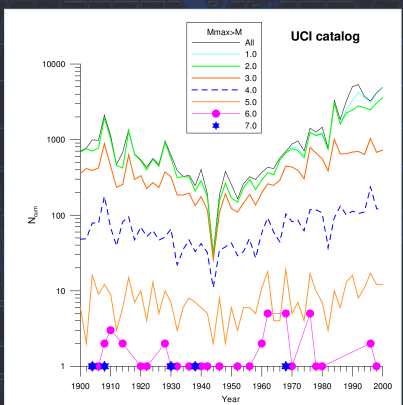
"http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm"

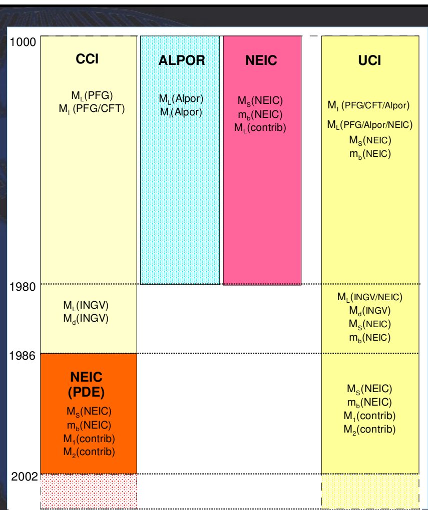
A complete archive of predictions is made accessible to a number of scientists, with the goal to accumulate a collection of correct and wrong predictions, that will permit to validate the considered methodology.

Current predictions are protected by password. Although these predictions are intermediate-term and **by no means imply a "red alert"**, there is a legitimate concern about maintaining necessary confidentiality.

CN and M8S algorithms in Italy: the input data

- CN and M8S algorithms make use of the information contained in **routinely published earthquake catalogs**.

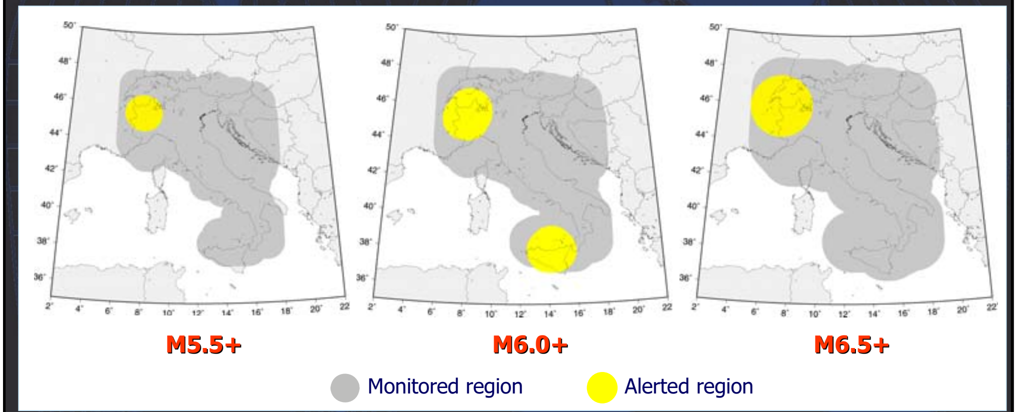




- Italian catalog (basically PFG and Alpor data) is used up to 1985, mainly to set up the algorithms parameters
- **Global data from NEIC are used since 1986 to perform routine real time predictions**

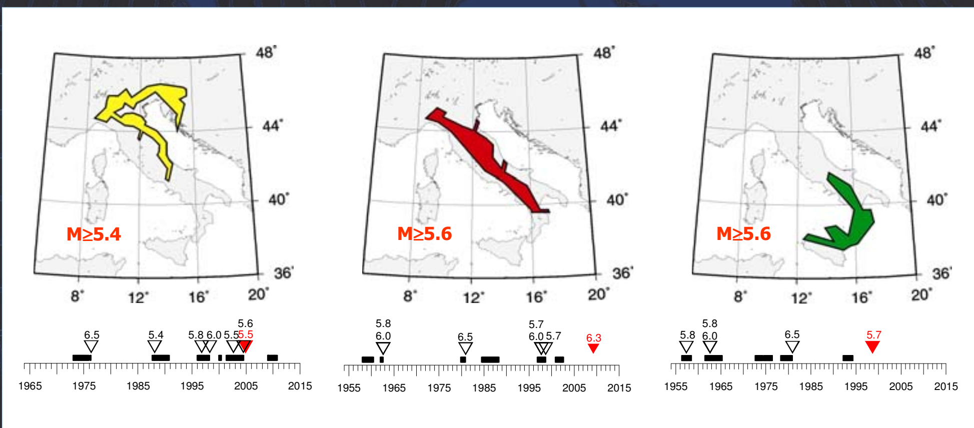
Algorithm M8S in Italy

- Predictions for Italy are performed for three different magnitude ranges, namely M6.5+, M6.0+ and M5.5+, where M_0+ indicates the magnitude range: $M_0 \le M \le M_0+0.5$.



Algorithm CN in Italy

- The algorithm CN analyses the seismic activity inside a set of predefined polygons (regions), outlined strictly following the seismotectonic zoning (*Peresan, Costa & Panza., 1999, Pageoph, 154*)



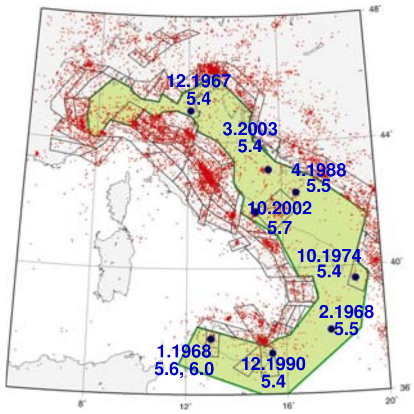
CN application to the Adriatic region

ADRIA REGION

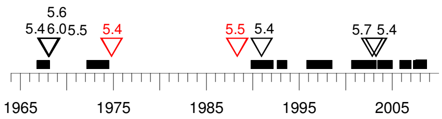
Prediction of the events with M≥5.4

Updated to 1-11-2009
(next update: 1-1-2010)
TSP: 1964 – 1999
Predictions regularly updated since January 2003

78% predicted events (7 out of 9)
TIP: 36.4% of total time
5 false alarms



▬ TIPs
▽ Strong Earthquakes predicted
▽ Failure to predict

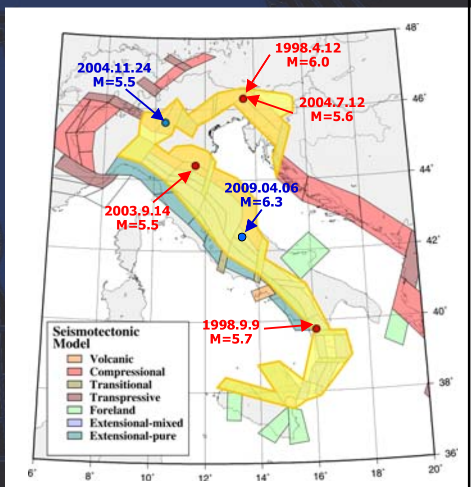


The CN real-time monitoring of seismic flow

Real-time testing 1998-2010

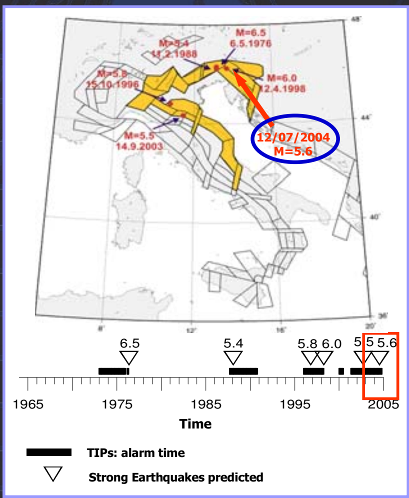
Earthquakes occurred within the space-time-magnitude volume monitored by CN since 1998

Date	Latitude, °N	Longitude, °E	Depth, KM	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



Updated to May 1 2010 (next updating July 1 2010)

The CN real-time monitoring of seismic flow



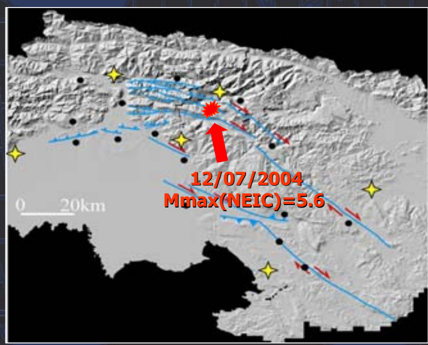
The Bovec earthquake - July 12 2004

Alarmed area for M≥5.4 by CN algorithm

(Peresan et al., ESR,2005)

(As on 1 July 2004)

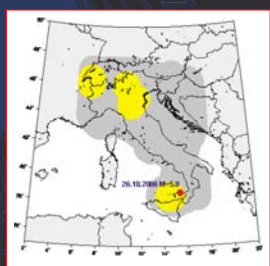
Southeastern Alps – External Dinarides
InSAR - CGPS - Campaign GPS monitoring

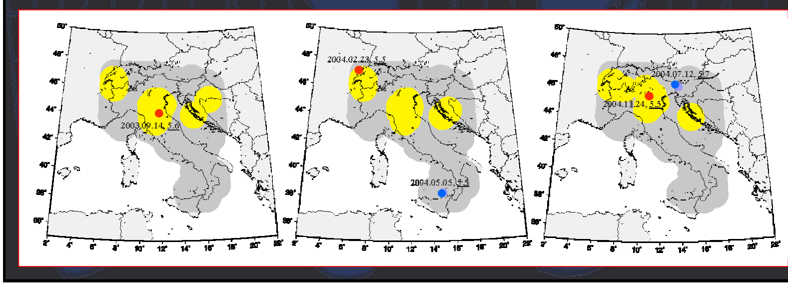


The M8S real-time monitoring of seismic flow

Real-time testing M5.5+, 2002-2010

Date	Latitude, °N	Longitude, °E	Depth, KM	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} ≥5.5 occurred since July 2003

Updated to January 1 2010

A review of the application of the algorithms CN and M8 to the Italian territory, about the input data, as well as detailed information about their performances is provided in:

***"Intermediate-term middle-range earthquake predictions in Italy: a review"* (2005),** by A. Peresan, V. Kossobokov, L. Romashkova and G.F. Panza. Earth Science Reviews (69, 97-132, 2005).

Evaluating prediction results

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)	36	2/2	40	1/2	39	9/14
Forward (2002-2010)	35	0/0	39	0/1	20	5/9
All together (1972-2010)	36	2/2	40	1/3	35	14/23

Algorithm M8s predicted 60% of the events occurred in the monitored zones in Italy, i.e. 17 out of 28 events occurred within the area alerted for the corresponding magnitude range. The confidence level of M5.5+ predictions since 1972 has been estimated to be above 98%; no estimation is yet possible for other magnitude levels.

(updated to January 1 2010;
next updating July 1 2010)

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 – 2010)	27	4/6	95
All together (1954 – 2010)	29	12/14	>99

* Central and Southern regions only

Algorithm CN predicted 12 out of the 14 strong earthquakes occurred in the monitored zones of Italy, with less than 30% of the considered space-time volume occupied by alarms.

(updated to May 1 2010;
next updating July 1 2010)

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

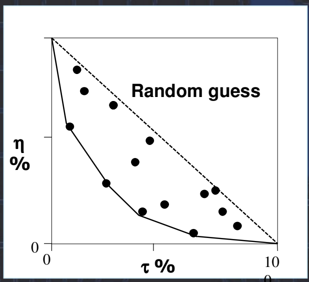
Intermediate-term middle-range earthquake prediction

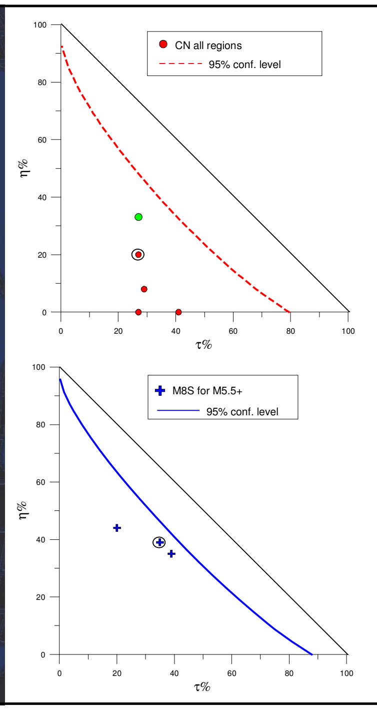
Evaluation of prediction results

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 November 1 2009 (next updating January 1 2010)

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.

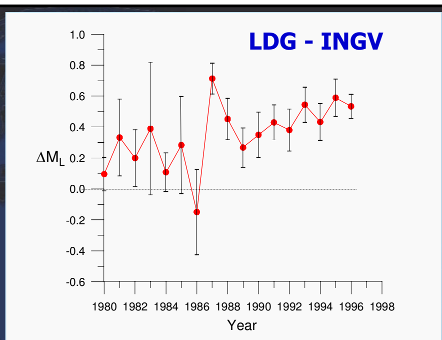
The Italian testing region: Rules of the Game and some basic shortcomings

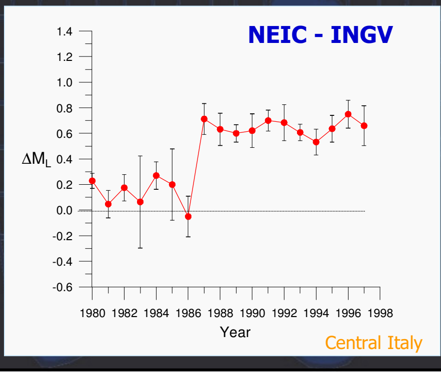
1. **Errors in the input data.** *"Models will be evaluated against the authoritative observed data supplied by INGV […]. The INGV ML magnitude scale will be considered the reference scale for model development and testing."*
2. **Missing methods/criteria to compare** different alarm-based models and 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

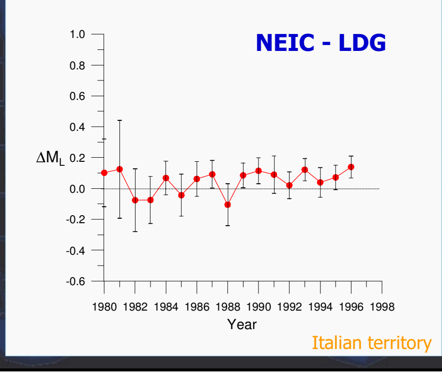
Local magnitude comparison: Italian territory

Yearly Average differences for $M_L \geq 3.0$ (from previous studies)

Peresan, Panza, Costa (2000) – GJI, 141, 425-437



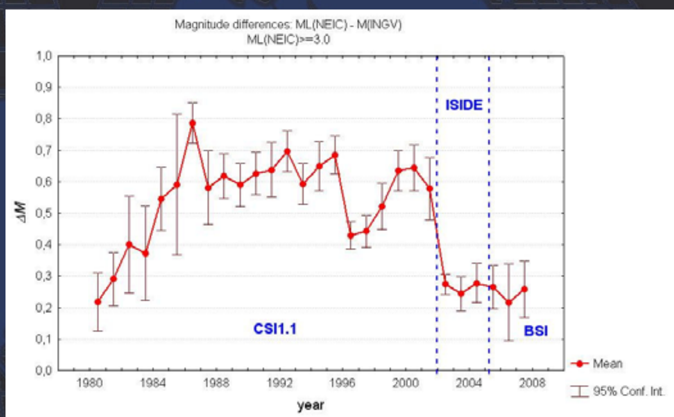




Local magnitude comparison: CSEP testing region

Average magnitude differences between NEIC (PDE) and INGV (CSEP) data set evidence a significant M_L(INGV) magnitude change in the period 1986-2002

Yearly Average differences M_L(NEIC) – M(INGV)

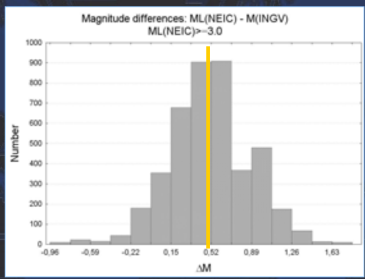


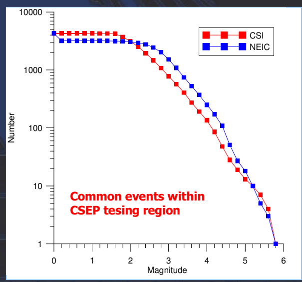
The average M_L(INGV) underestimation in 1986-2002 is well comparable to that evidenced so far by *(Peresan, Panza & Costa, GJI 2000)* and confirmed by *(Gasperini et al., 2001)*

CSI1.1.- Castello, B., et al. (2007). Bull. Seism. Soc. Am. 97(1B): 128-139.

Local magnitude comparison: CSEP testing region

M_L(NEIC) – M_L(CSI)
1986-2002

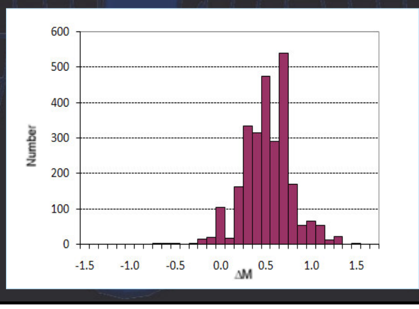




An average M_L(CSI) underestimation of ≈ 0.5-0.6 is identified for events with M≥3

M(INGV/ISIDE) – M(INGV/CSI)
2002

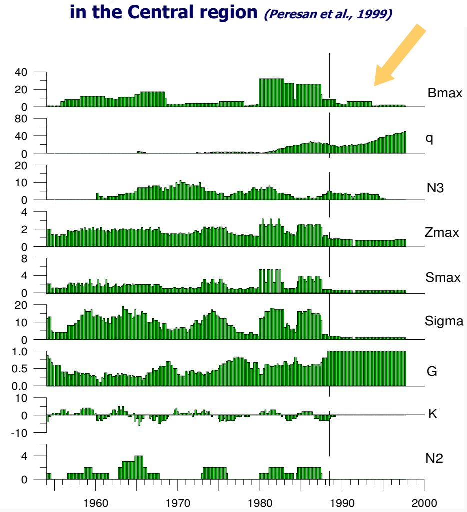
The heterogeneity of INGV magnitude estimates is supported by the cross-comparison of CSI1.1 and ISIDE bulletin, both available in 2002



CSEP testing in Italy: errors in the input data

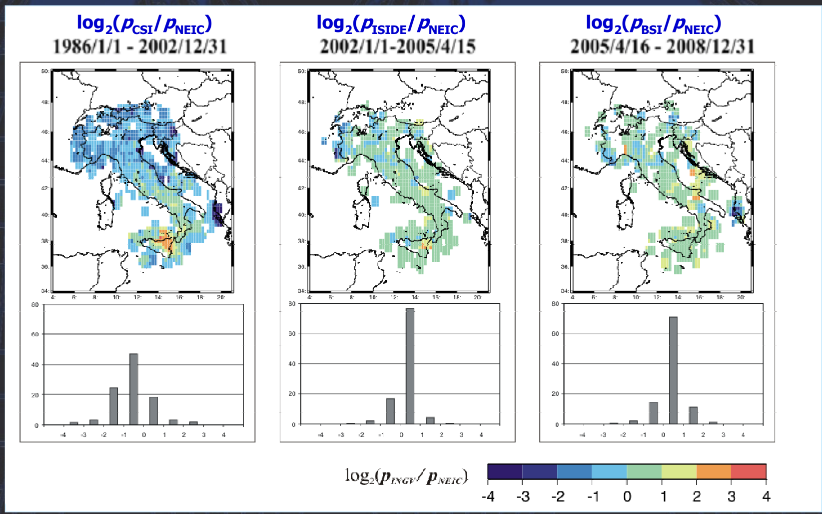
Existing heterogeneities in the input catalog may significantly affect any related characterization of seismicity and thus the detection of premonitory patterns

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

Spatial distribution analysis



Maps of the ratio of empirical spatial probability density distribution functions for earthquakes with M(INGV)≥3 reported in different INGV data sources within CSEP Testing Region and their density distributions (%). Values around 0 (i.e., comparable values of ***p***) indicate general agreement in recurrence density between INGV and NEIC data sets.

CSEP testing in Italy: errors in the input data

- **The comparative analysis of magnitudes reported by INGV and NEIC, evidenced an average underestimation of about 0.5 in the local magnitudes provided in CSI1.1 catalogue** *(Castello et al., 2007)* **during the period 1986-2002.**
- **The magnitude difference is well comparable to that detected so far** (*Peresan, Panza & Costa, GJI 2000*)**, and confirmed by a later work** *(Gasperini, Vannucci & Orlanducci, 2001),* **considering an earlier version of the Italian INGV data.**
- **Problem: the INGV data, that are proposed as the "authoritative" data source for CSEP testing in Italy and are the input data for various probabilistic prediction methods** *(e.g. Cinti, Faenza, Marzocchi e Montone. Geochem. Geophys. Geosyst., 2004; Faenza et al., 2003)* **, turn out to be heterogeneous over space and time.**

Evaluation of prediction results: CSEP Testing in Italy

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

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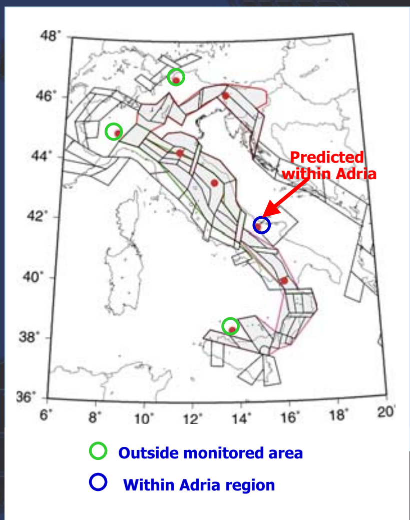
Evaluation of prediction results: examples of biased assessment

Some possible pitfalls in the analysis of prediction models:

1. Comparison of statistics achieved in real-time time testing to the model ones, with parameters adjusted a posteriori.
2. Scoring of the "target" events from outside the area of testing allows to create the illusion of low efficiency for some models.
3. Neglecting evident failures allows to create the illusion of high efficiency for some other models

➡ **No systematic formal analysis of prediction results**



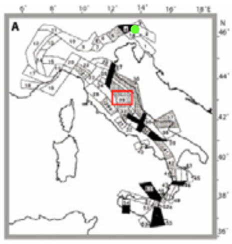
Evaluation of prediction results: examples of biased assessments

Neglecting evident failures creates the impression of high efficiency…

Bovec 1998 event (M=6.0) is inside Zone 4 that has the 2nd smallest probability in Table after Boschi et al. (1995).

Marzocchi (Annals of Geophys, 2008)

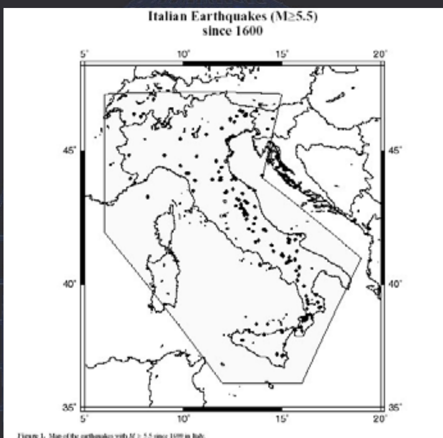
process modeled through a Poisson process.
Here, I do not deepen the physical implications that stand behind the choice to use different processes for different zones, but I just focus the attention on the forecasting made by Boschi *et al.* (1995). In particular, the model aimed forecasting the occurrence of the M 5.9+ next earthquakes in Italy for different time windows. The Umbria-Marche region has the sixth highest probability of occurrence in the interval 1995-2000 out of 20 regions (see fig. 1). In this respect, the occurrence of the 1997-1998 earth-



B

Zone	Last Event (mdyr)	Gauss Process 5 yr	Gauss Process 20 yr	Gauss Process 100 yr	Poisson Process 5 yr	Poisson Process 20 yr	Poisson Process 100 yr
4	05061976	0.00-0.05	0.01-0.21	0.31-0.91			
5	10181936				0.04-0.15	0.16-0.44	0.44-0.87
21	09071920				0.02-0.07	0-07-0.23	0.28-0.66
27	10301870	0.19-0.38	0.61-0.87	1.00-1.00			
28a	09101919				0.03-0.10	0.11-0.33	0.35-0.77
29	04261917				0.13-0.23	0.41-0.63	0.97-0.99
30	10301930				0.02-0.08	0.08-0.25	0.30-0.68
33	01131915	0.03-0.18	0.17-0.60	0.95-1.00			
34	10061762	1.00-1.00	1.00-1.00	1.00-1.00			
35	09261933	0.00-0.06	0.02-0.24	0.30-0.88			
36	08211962	0.00-0.06	0.01-0.17	0.20-0.84		0.09-0.25	
37	08101893				0.02-0.07		0.34-0.70
39	08141851	0.13-0.28	0.45-0.75	0.99-1.00			
41	11231980				0.06-0.13	0.22-0.41	0.64-0.88
44	12031887				0.05-0.12	0.19-0.40	0.58-0.87
46	05111947	0.01-0.11	0.06-0.40	0.69-0.99			
48	12281908				0.04-0.12	0.13-0.38	0.39-0.81
50	03051823	0.44-0.60	0.92-0.98	1.00-1.00			
53	08071846	0.87-0.94	1.00-1.00	1.00-1.00			
54	01151968	0.00-0.04	0.01-0.15	0.13-0.72			

Fig. 1. Boschi *et al.*'s (1995) forecasts. A) Map of the regionalization used. B) The probabilities estimated for M 5.9+ at different forecasting time windows (5, 20, and 100 years) are reported; the intervals represent the 68% confidence intervals. The red boxes mark the region where Umbria-Marche earthquakes occurred.



Probability map for the occurrence for a M ≥ 5.5 event – 10 years

input data: 1950-2002

● Events with M larger than 5.5 since 2003

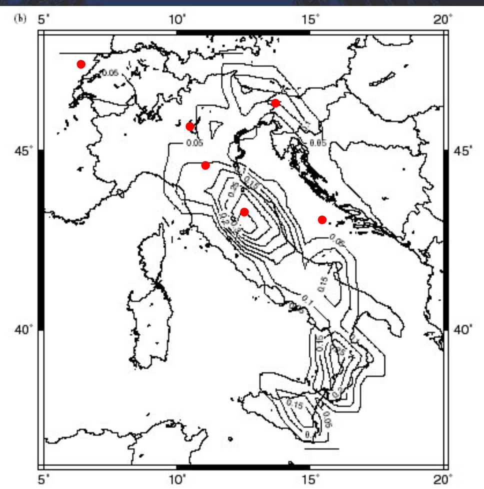


Figure 6. (*Continued.*)

Evaluation of the space-time volume of alarm is also necessary…

(Faenza, Marzocchi & Boschi, GJI 2003)

Pattern Recognition of Earthquake Prone Areas

Pattern Recognition of Earthquake Prone areas

- Pattern recognition technique is used to identify, independently from seismicity information, the sites where strong earthquakes are likely to occur.
- Assumption: strong events nucleate at the nodes, specific structures that are formed around intersections of lineaments.

↓

- The nodes are defined by the Morphostructural Zonation Method, based on: topography, tectonic data, geological data.

Pattern Recognition of Earthquake Prone areas

- **Earthquake Prone Areas are identified evaluating the following characteristics :**
  - **Topographic parameters**
    (elevation, slope)
  - **Geological parameters**
    (area covered by quaternary sediments)
  - **Parameters from the morphostructural map**
    (rank and number of lineaments)
  - **Morphological parameter**
    (morphology within each node)
  - **Gravity parameters**
    (Bouguer anomaly)

Pattern Recognition of Earthquake Prone areas

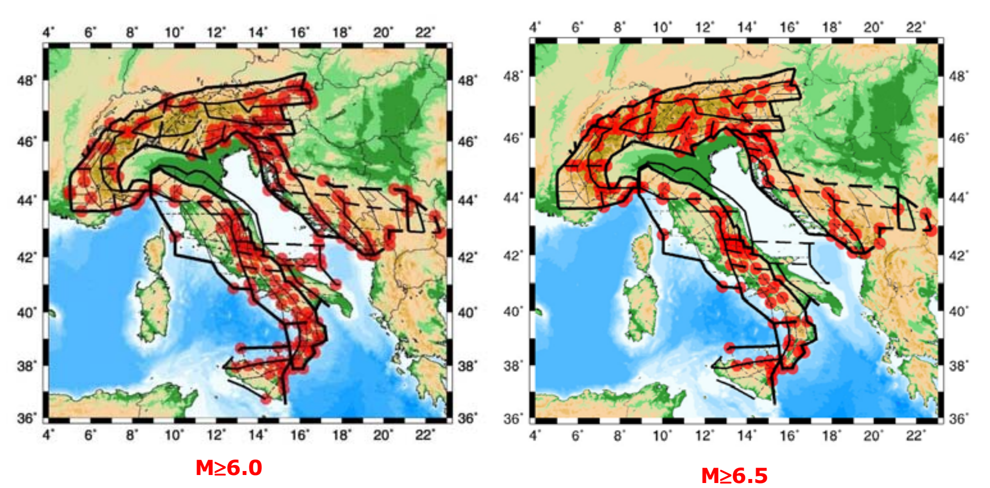
- **The Earthquake Prone Areas are identified evaluating, among the others, the following topographic characteristics :**
  - **Elevation and its variations in mountain belts and watershed areas;**
  - **Orientation and density of linear topographic features;**
  - **Type and density of drainage pattern.**
- **These features indicate higher intensity in the neotectonic movements and increased fragmentation of the crust at the nodes.**

Pattern Recognition of Earthquake Prone areas

- The fact that earthquakes are nucleated at the nodes was first established from observations in the Pamirs and Tien Shan (*Gelfand et al.*, 1972).

- This approach has been applied to many regions of the world. The predictions made in the last 3 decades have been followed by many events (84% of the total) that occurred in some of the nodes previously recognized to be the potential sites for the occurrence of strong events.

Pattern Recognition of Earthquake Prone areas

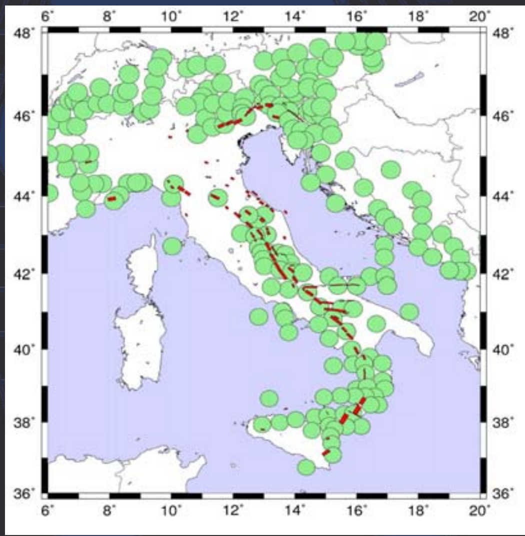


Morphostructural Zonation
and identified earthquake prone areas

Active faults associated with earthquake prone areas

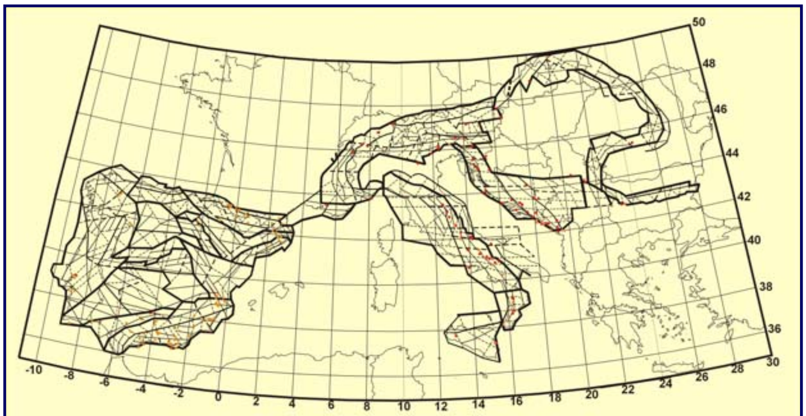
Formal criteria have been defined to:

- associate the identified seismogenic nodes with specific source properties (i.e. focal mechanisms);
- Associate the nodes with the active faults as reported in the DISS3 database (http://diss.rm.ingv.it/diss/)



Nodes and active faults from DISS3

Lineaments (lines) and epicenters (dots) of strong earthquakes in the Mediterranean area



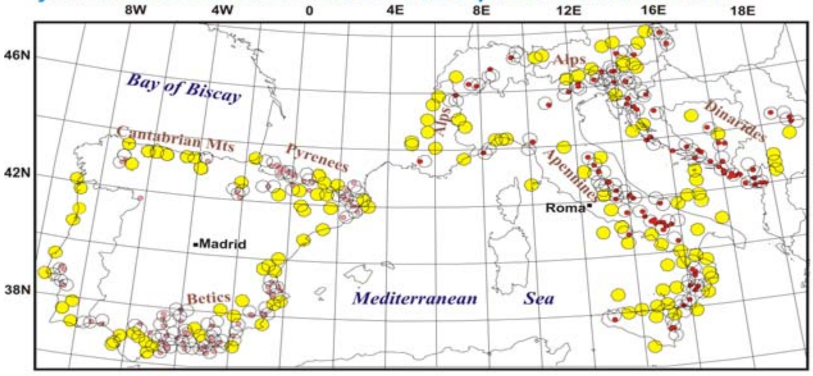
Morphostructural Zonation Map

Gorshkov et al. (2002, 2004)

Recognition of nodes where strong earthquakes may nucleate in the Mediterranean area

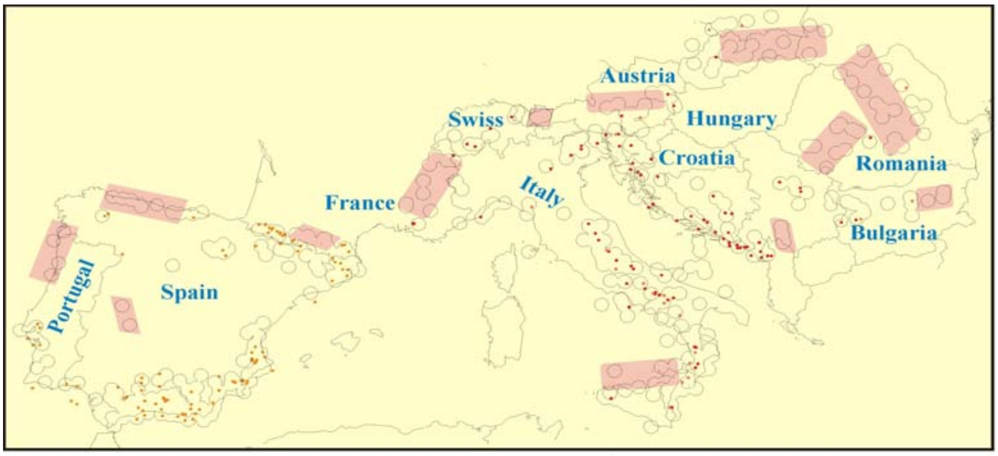
Target magnitudes: $M \geq 6.0$ - Alps, Apennines and Dinarides
$M \geq 5.0$ - Iberia

circles show earthquake-prone nodes
dots mark target earthquakes
yellow marks the nodes where such earthquakes are still unknown



References
Gorshkov A.I., Panza G.F., Soloviev A.A. & Aoudia A. (2002). Morphostructural zoning and preliminary recognition of seismogenic nodes around the Adria margin in peninsular Italy and Sicily. *JSEE:* Spring 2002, 4, No.1, 1-24.
Gorshkov A.I., Panza G.F., Soloviev A.A., Aoudia A. (2004). Identification of seismogenic nodes in the Alps and Dinarides. *Boll.Soc.Geol.Ital.* 123, 3-18

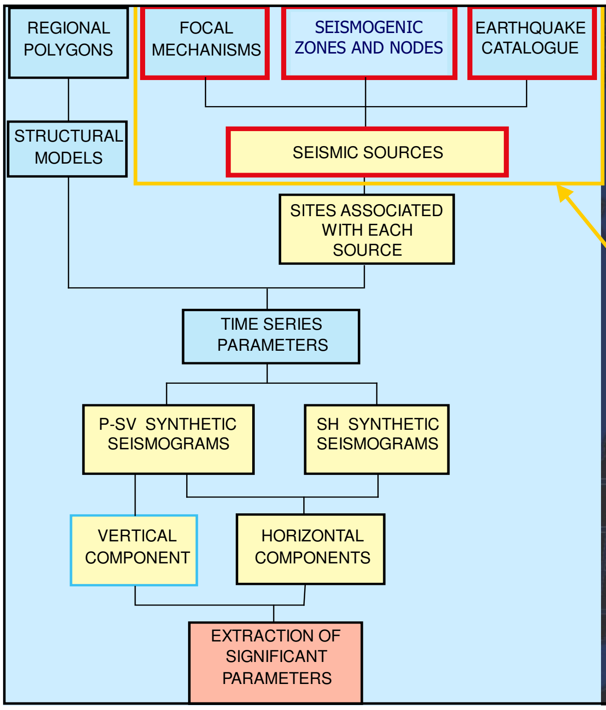
Is the information on observed seismicity sufficient to identify the sites where large earthquakes may occur?



Integrated Neo-deterministic Hazard Scenarios

Regional ground shaking scenarios
(ground motion at bedrock)

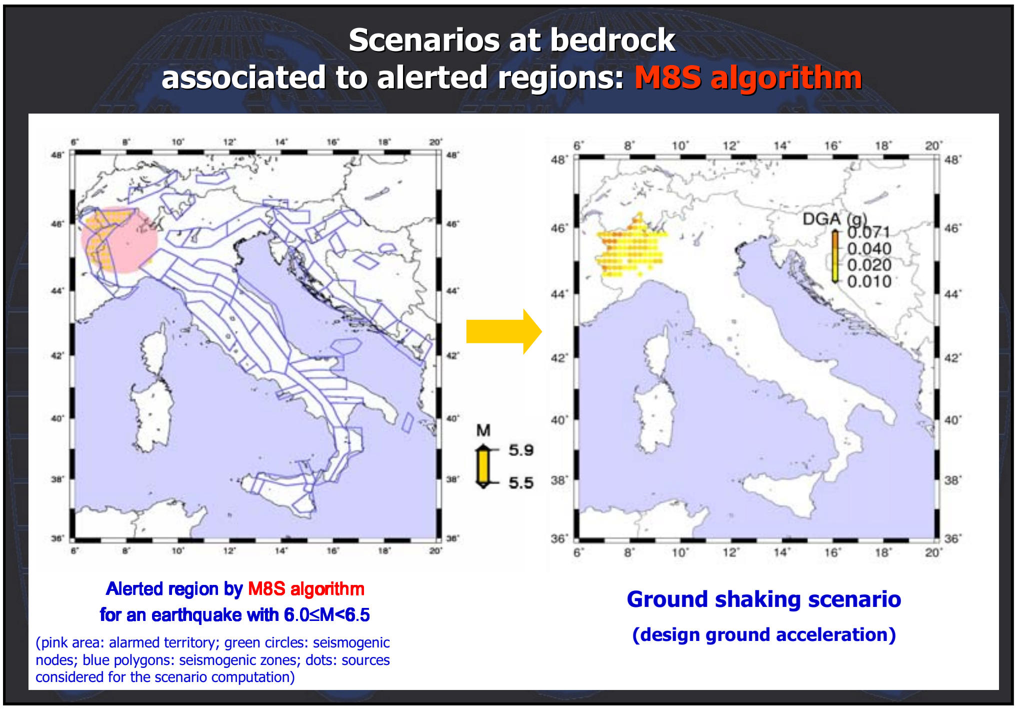
- Scenarios associated to alerted CN and M8S regions (+ time)
- Scenarios associated to seismogenic nodes

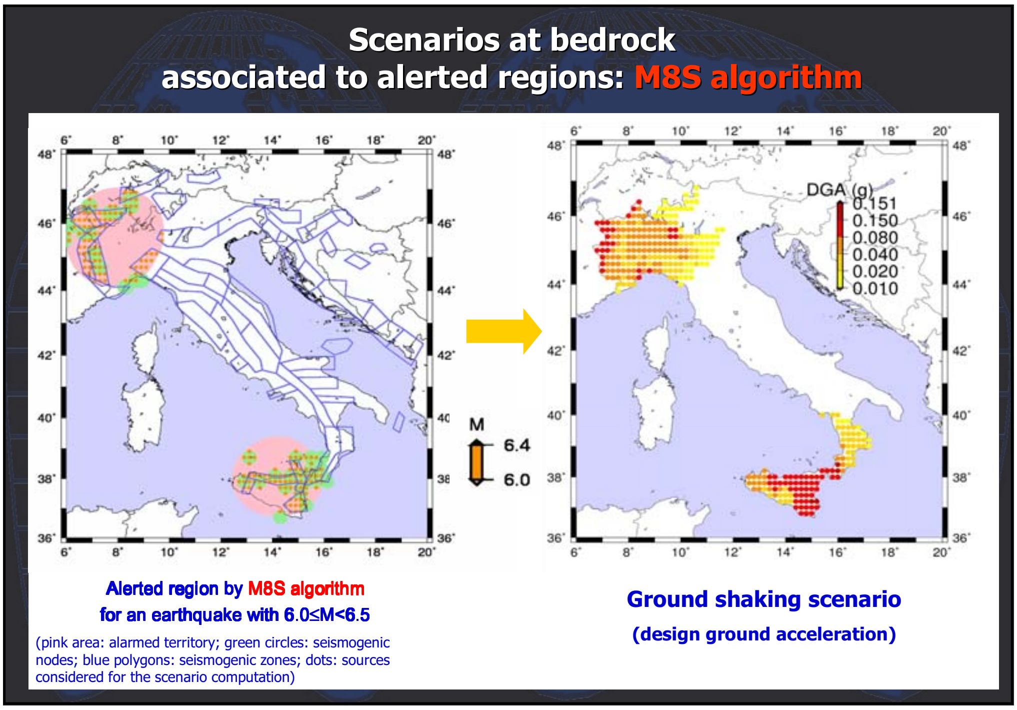


Flow-chart of the neo-deterministic hazard method

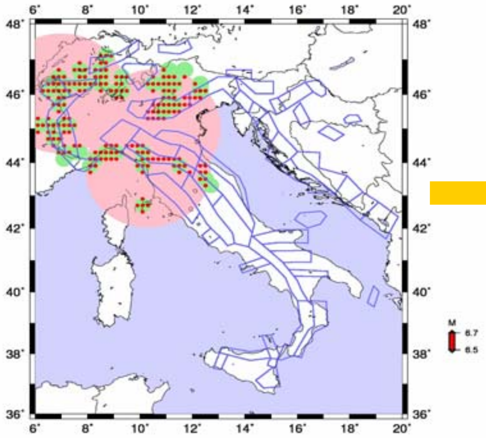
Seismic sources are defined based on seismic history, seismotectonic and seismogenic nodes.

Seismic sources are then selected within the alerted regions (**CN or M8S**) or within the **earthquake prone nodes**.


Scenarios at bedrock
associated to alerted regions: M8S algorithm
M
5.9
5.5
DGA (g)
0.071
0.040
0.020
0.010
Alerted region by M8S algorithm
for an earthquake with 6.0≤M<6.5
(pink area: alarmed territory; green circles: seismogenic nodes; blue polygons: seismogenic zones; dots: sources considered for the scenario computation)
Ground shaking scenario
(design ground acceleration)

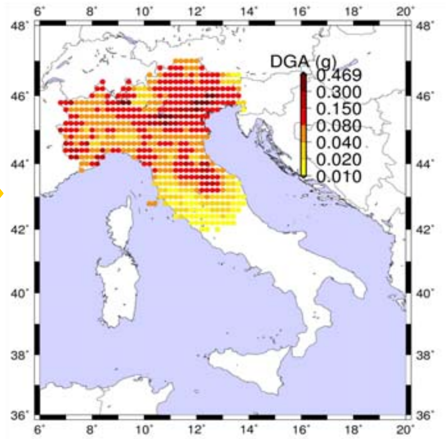

Scenarios at bedrock
associated to alerted regions: M8S algorithm
M
6.4
6.0
DGA (g)
0.151
0.150
0.080
0.040
0.020
0.010
Alerted region by M8S algorithm
for an earthquake with 6.0≤M<6.5
(pink area: alarmed territory; green circles: seismogenic nodes; blue polygons: seismogenic zones; dots: sources considered for the scenario computation)
Ground shaking scenario
(design ground acceleration)

Scenarios at bedrock associated to alerted regions: M8S algorithm



Alerted region by M8S algorithm for an earthquake with 5.5≤M<6.0

(pink area: alarmed territory; green circles: seismogenic nodes; blue polygons: seismogenic zones; dots: sources considered for the scenario computation)



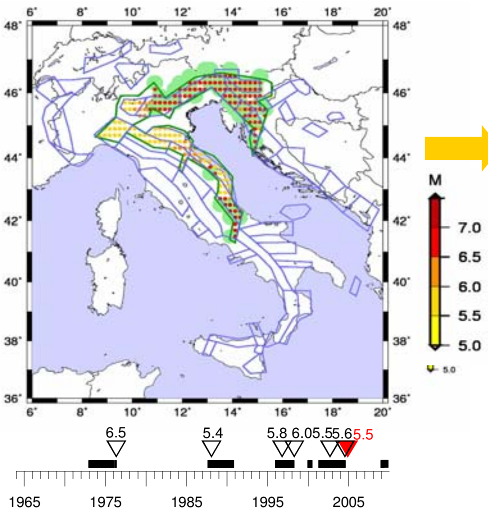
Ground shaking scenario

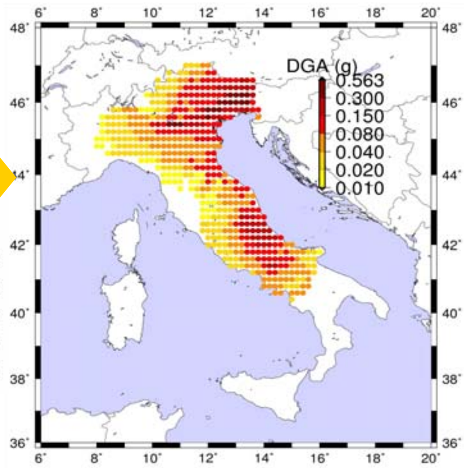
(design ground acceleration)

Scenarios at bedrock associated to alerted regions: CN algorithm

Northern Region

Prediction of earthquakes with M≥5.4





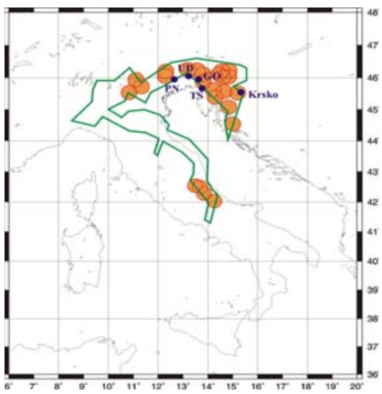
Ground shaking scenario

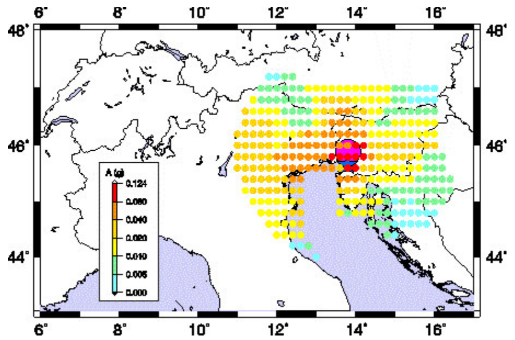
Scenario associated to earthquake prone nodes

Example: node determining the maximum ground motion in the city of Trieste

corresponding to an earthquake with M=6.5
(compatible with seismic history and seismotectonics)

M≥6.5

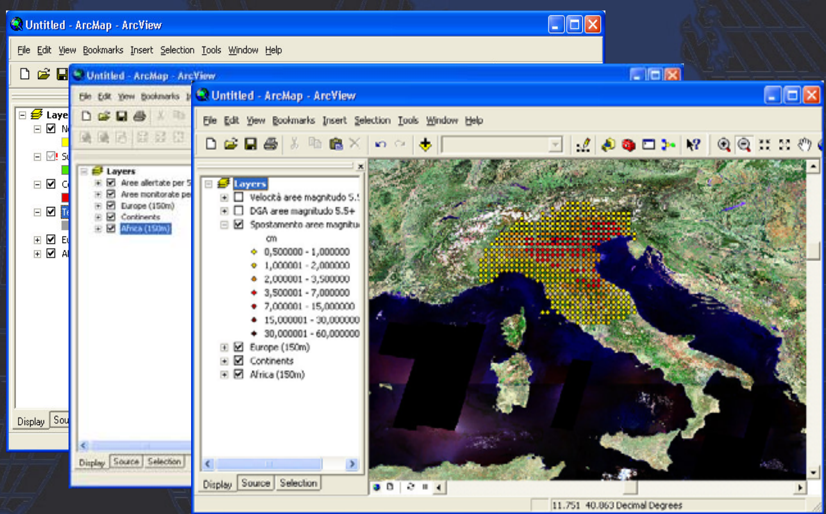




PGD (cm)	PGV (cm/s)	DGA (g)	I_{max} computed ING	I_{max} computed ISG	I_{max} observed
2.0 – 3.5	4.0 – 8.0	0.08-0.15	IX	VIII	VII

Peak Ground Displacement (PGD), Peak Ground Velocity (PGV), Design Ground Acceleration (DGA) and maximum computed intensity (I_{max} computed), estimated using the conversion tables proposed by Panza et al. (2001). The observed intensity in the city of Trieste is the same in the ING and ISG data sets.

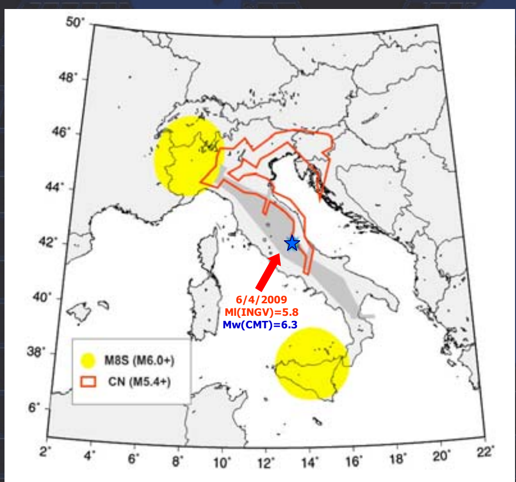
SISMA: products GIS interface



Regional Bedrock Ground Shaking Scenarios

The Aquilano earthquake
6th April 2009

The Aquilano earthquake, 6th April 2009



Alarmed areas by CN and M8S algorithms (as on 6 April 2009)

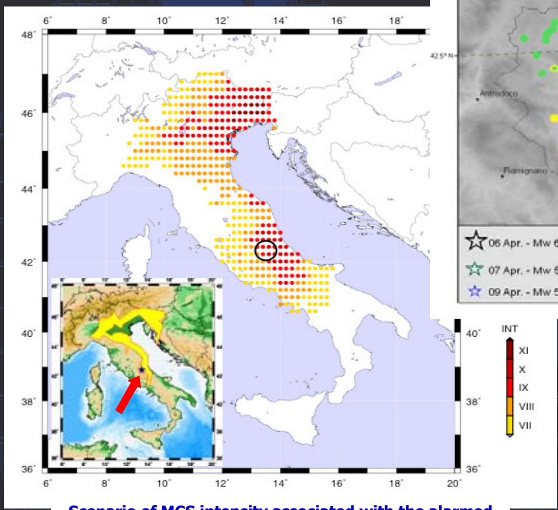
CN Algorithm

- The L'Aquila earthquake turns out to be a failure to predict within the Central Region
- The epicenter was about 10 km outside the alarmed CN territory (TIP declared for M≥5.4 within Northern region from 1.3.2009 to 1.3.2010)

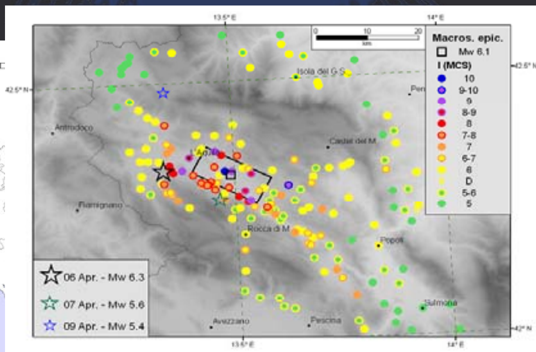
M8S Algorithm

- The Aquilano earthquake occurred outside the areas identified by M8S for the magnitude range M6.0+

The Aquilano earthquake, 6th April 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



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

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

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 and validation of CN and M8S predictions.**

- **The national scale scenarios of ground shaking associated with alerted areas, along with the time information provided by intermediate-term predictions, supply decision makers an objective tool indicating priorities for timely mitigation actions (e.g. retrofitting of critical structures).**

- **Neo-deterministic hazard assessment and pattern-recognition of earthquake prone areas procedures are especially useful as a mean of prevention in areas where historical and instrumental information is scarce.**

Conclusions

- The neo-deterministic seismic hazard procedure makes it possible to use wide geophysical data sets, including EO data, as well as the current knowledge of the physical process of earthquake generation and wave propagation in realistic anelastic media, and do not need to rely only on macroseismic observations.

- The seismic input (complete seismograms) provided by the realistic modeling of ground motion permits the engineering non-linear dynamic analysis of relevant structures (e.g. power plants, bridges, dams).