The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

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2060-56

Advanced School on Non-linear Dynamics and Earthquake Prediction

28 September - 10 October, 2009

Intermediate-term middle-range earthquake prediction: real-time testing in Italy & surrounding regions

A. Persesan

Dept. of Earth Sciences
University of Trieste
ICTP
Trieste

ICTP
Advanced School on Non-linear Dynamics and Earthquake Prediction
Trieste - Italy, 28 September - 10 October 2009

Intermediate-term middle-range earthquake prediction: real-time testing in Italy and surrounding regions

Antonella Peresan

Contributed:
V. Kossobokov, L. Romashkova, I. Rotwain, G.F. Panza

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Algorithms for middle-range intermediate-term prediction

Algorithms fully formalized and globally tested for prediction are:

- **CN algorithm** (*Gabrielov et al., 1986; Rotwain and Novikova, 1999*)
- **M8 algorithm** (*Keilis-Borok and Kossobokov, 1987; Kossobokov et al., 1999*)

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

Algorithms for middle-range intermediate-term prediction

The algorithms are based on a set of empirical functions 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**

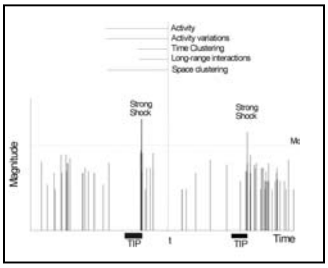
These methods are designed according to a pattern-recognition scheme, to define space and time limits where a disastrous earthquake has to be expected based on detectable inverse cascade of seismic process, at different space and time ranges.

Functions of the seismic flow

The functions of the seismic flow are computed over the sequence of main shocks within a predefined region.

Functions are normalized by minimal magnitude cutoff M_{min}, defined by one of the two conditions:

- **$M_{min} = M_0 - C$, C: constant**
- **M_{min} such as $N(M_{min}) = A$, A: constant rate of activity**



Normalization is necessary to ensure uniform application with the same set of adjustable parameters in regions of different seismic activity.

Functions of the seismic flow: magnitude ranges

CN algorithm

	N2	N3	K	G	Sigma	Smax	Zmax	q	Bmax
Mmin	m3	m2	m2	m2	m1	m1	m1	m2	-
Mmax	-	-	-	-	Mo-1	Mo-1	Mo-1	-	-

Magnitude cutoff for normalization of functions, based on rate of activity: m1(a=3.0) m2(b=1.4) m3(c=0.4)

M8 algorithm

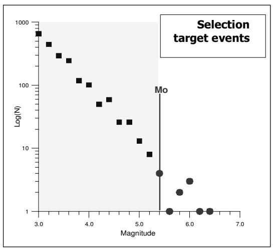
	N1	L1	Z1	N2	L2	Z2	Bmax
Mmin	M(10)	M(10)	M(10)	M(20)	M(20)	M(20)	-
Mmax	-	-	Mo-0.5	-	-	Mo-0.5	Mo-0.2

CN algorithm in Italy

Rules for CN application and selection of target events

- **Area:** 5L-10L (L is the source linear dimension)
- **Magnitude of completeness**:
  - Yearly average number of events with $M \geq M_c$ must be>3
  - $M_o - \Delta M \geq M_c$ where $\Delta M \approx 3$
- **Magnitude threshold M_o**
  - The return period for target earthquakes, with $M \geq M_o$, is ≈6-7 years
  - M_o corresponds to a minimum of N(M)

➡ CN makes use of the information given by small and moderate earthquakes, following the GR law (having quite a good statistic), to predict the stronger earthquakes, which are anomalous events (i.e. do not follow the GR law) for the same area.

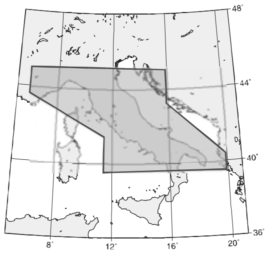


First application of CN algorithm in the Italian area

Italian Region

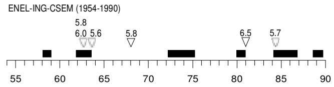
(Keilis-Borok et al., 1990, Pageoph, 134)

- Regionalization defined based on the completeness of the used catalog ENEL-ING-CSEM, partially covering the Adriatic sea
- Prediction of the events with M≥5.6
- TSP:1954-1986; TIP diagnosis: 1954-1990
- Results: 80% predicted events (4 out of 5) TIP: 26.0% of total time



▽ Strong Earthquakes with M≥5.6

▬ TIPs



Rules for the definition of CN regions according to the seismotectonic model

A single region includes:

1. adjacent zones with the same seismogenic characteristics (e.g. only compressive or only extensive);

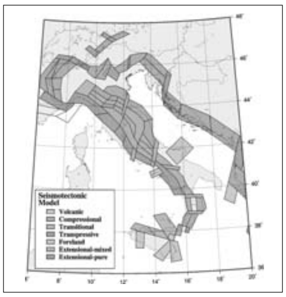
2. zones with transitional properties.

A transitional zone is included in a region if:

1. it is between zones of the same kind;

2. it is at the edges of the region and the space distribution of the aftershocks reveals a possible connection.

(Peresan, Costa & Panza., 1999, Pageoph, 154)



Seismotectonic zoning of Italy defined by GNDT (Gruppo Nazionale per la Difesa dai Terremoti)

(Meletti et al., Pageoph, 2000)

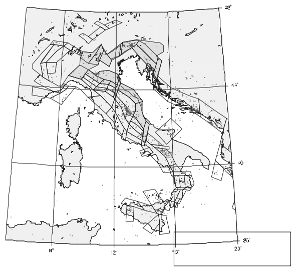
CN regionalization for the Italian territory

NORTHERN REGION

Prediction of the events with M≥5.4

Updated to 1-9-2009
(next update: 1-11-2009)

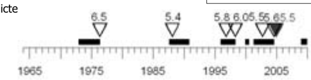
TIP: 27.6% of total time



▬ TIPs

▽ Strong Earthquakes predicte

▽ Failure to predict



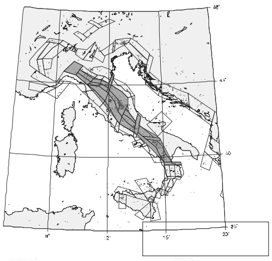
CN regionalization for the Italian territory

CENTRAL REGION

Prediction of the events with M≥5.6

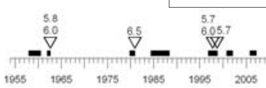
Updated to 1-9-2009
(next update: 1-11-2009)

TIP: 21.2% of total time



▬ TIPs

▽ Strong Earthquakes predicted



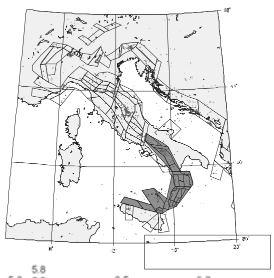
CN regionalization for the Italian territory

SOUTHERN REGION

Prediction of the events with M≥5.6

Updated to 1-9-2009
(next update: 1-11-2009)

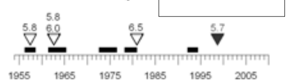
TIP: 27.2% of total time



▬ TIPs

▽ Strong Earthquakes predicted

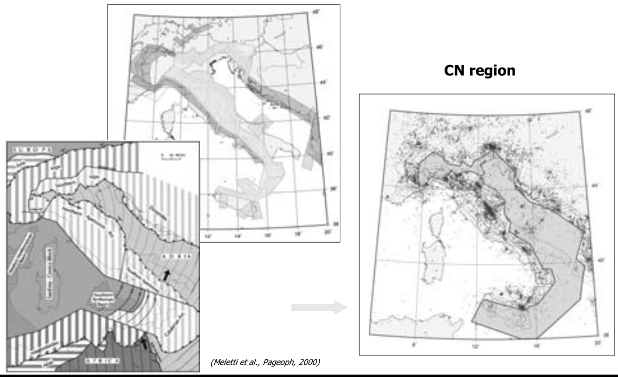
▽ Failure to predict



The regionalization based on the seismotectonic model

- The seismotectonic model, supported by kinematic arguments, can be viewed as a useful tool that permits to optimise the selection of the fault systems involved in the generation of strong earthquakes.

Adriatic Region



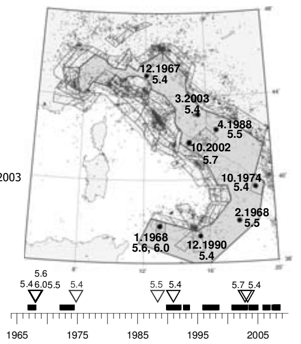
CN application to the Adriatic region

ADRIA REGION

Prediction of the events with M≥5.4

Updated to 1-9-2009
(next update: 1-11-2009)
TSP: 1964 – 1999
Predictions regularly updated since January 2003

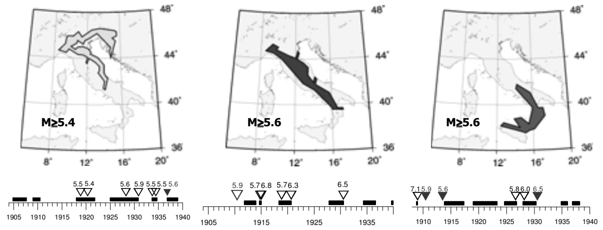
78% predicted events (7 out of 9)
TIP: 36.2% of total time
6 false alarms



CN algorithm in Italy: stability experiments

Algorithm CN in Italy: stability experiments

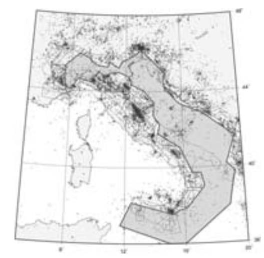
"Seismic history" experiment



TSP:1964-1998	TSP:1954-1998	TSP:1954-1998
TIP diagnosis: 1904-1940	**TIP diagnosis: 1904-1940**	**TIP diagnosis: 1908-1940**
86% predicted events (6 out of 7)	84% predicted events (5 out of 6)	50% predicted events (3 out of 6)
TIP: 48.0% of total time	TIP: 28.7% of total time	TIP: 46.8% of total time

Peresan, Vaccari, Romanelli, Panza (2005) - Atti dei Convegni Lincei. 218, 263-287.

CN algorithm: stability test for the Adria region



TIP diagnosis: 1964-2006.11

M_0=5.4	UCI catalog				
End of TSP	n/N	η	τ	ξ	κ
2003-01	6/8	25.0%	31.3%	56.3%	45.0%
1999-01	6/8	25.0%	31.3%	56.3%	45.0%
1991-01	6/8	25.0%	28.2%	53.2%	40.0%
1988-05	6/8	25.0%	34.4%	59.4%	45.0%

n = number of predicted earthquakes with M≥5.4
N = total number of main shocks with M≥5.4
η = n/N statistic of failures to predict
$\tau = \tau_\Sigma$ /T statistic of alarm time
κ= k/K statistic of false alarms

To evaluate the stability of prediction results, the time period (TSP) used to adjust the algorithm thresholds, is progressively reduced.

The results of the experiment show that the *(η+τ)* is well below the value (η+τ)=100% corresponding to the results of a random guess.

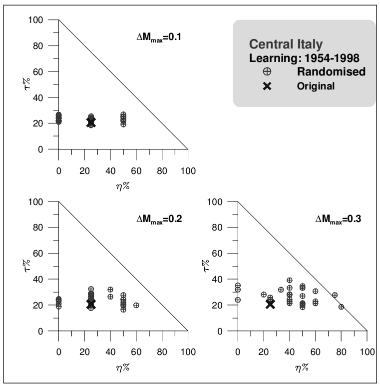
The total error is comparable with that obtained on a global scale (about 50%)

Stability of TIPs diagnosis with respect to random errors in magnitude

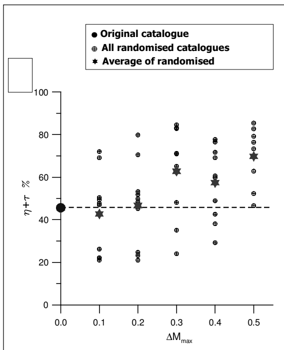
Central Italy

$\eta = n/N$: the rate of failures-to-predict

$\tau = t/T$: the rate of time of alarms



Results obtained with the randomised catalogue



Event date	M	N_S, %	N_P, %
23.11.1980	6.5	100.0	66.7
21.8.1962	6.0	100.0	93.3
26.9.1997	6.0	100.0	40.0
9.9.1998	5.7	83.3	56.0
19.9.1979	5.5	23.3	0.0
5.5.1990	5.5	12.0	0.0
7.5.1984	5.4	0.0	0.0

List of earthquakes with M≥5.6 Central Italy: 1950-1999

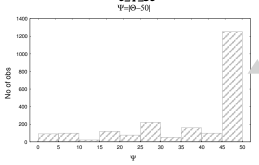
N_S: percentage of times each event is a strong event ($M \geq M_o = 5.6$)

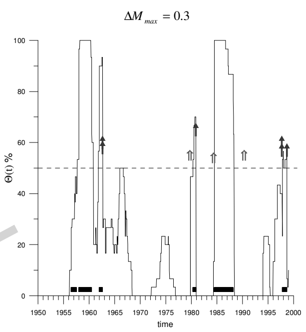
N_P: percentage of times each event is predicted (catalogues randomised with $\Delta M_{max} = 0.3$)

Stability of TIPs diagnosis with respect to random errors in magnitude

Central Italy

Ψ: percentage of tests for which the recognition of the time *t* does not change with respect to its average value
$0 \leq \Psi \leq 50$
$\Psi = |\Theta - 50|$





Θ(t): percentage of tests for which the time *t* belongs to a TIP

Peresan, Rotwain, Zaliapin, Panza , PEPI, 130 (2002)

Stability of CN predictions with respect to random errors in magnitude

- **The results of prediction remain stable for $\Delta M_{max} < 0.3$.**
- **To guarantee the stability of the results, the thresholds setting period must be long enough to include a significant sample of dangerous and non dangerous intervals of time.**
- **The identification of TIPs is very stable during most of the time and the randomisation does not introduce spurious alarming patterns associated with the occasionally strong events.**
- **The quality of predictions is mainly controlled by the percentage of failures to predict, which depends on the changes in the number of strong earthquakes.**

Peresan, Rotwain, Zaliapin, Panza , PEPI, 130 (2002)

M8S algorithm in Italy

Algorithm M8S

- The M8 algorithm, analyses the seismic activity inside a set of Circles of Investigation, CIs, with radius normalized by the linear size of the events to be predicted, i.e. proportional to magnitude threshold M_0.
- A hierarchy of predictions is usually delivered for different magnitude ranges M_0+, considering values of M_0 with an increment of 0.5 (i.e. M_0+ indicates the magnitude range: $M_0 \leq M \leq M_0+0.5$).

Algorithm M8S

- A spatially stabilized variant of the algorithm M8 has been proposed , namely M8s algorithm, where the seismicity is analysed within a dense set of overlapping circles covering the monitored area (*Kossobokov et al., JSEE 2002*).
- The territory is scanned with a set of small circles distributed over a fine grid, with the radius of the small circles approximately equal the grid spacing and to the linear dimensions of the source of target events.

Algorithm M8S : steps of the analysis

1. The seismically active grid points are then selected by the condition that the average annual rate of seismic activity, within the small circle, is above a given threshold.
2. The grid points where data are insufficient for the application of M8 algorithm and isolated grid points are excluded.
3. The M8 algorithm is then applied with the circles of investigations, CIs, centred at each of the selected grid points.
4. An alarm is declared for a CI only if the overwhelming majority (more than 75%) of the CIs centred at the neighbouring grid points are also in state of alarm.

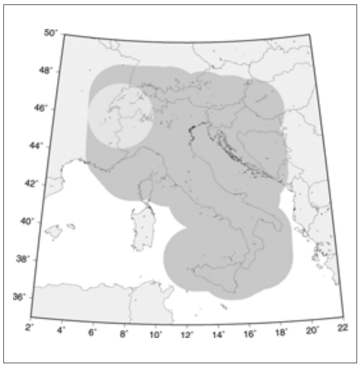
M8S algorithm in Italy

Magnitude:
M≥ 6.5

Radius of CI:
192 Km

Monitored region

Alerted region



Predictions as on: 1-7-2009

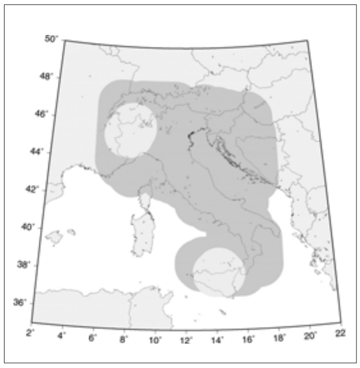
M8S algorithm in Italy

Magnitude:
M≥ 6.0

Radius of CI:
138 Km

Monitored region

Alerted region



Predictions as on: 1-7-2009

M8S algorithm in Italy

Magnitude:
M≥ 5.5

Radius of CI:
106 Km

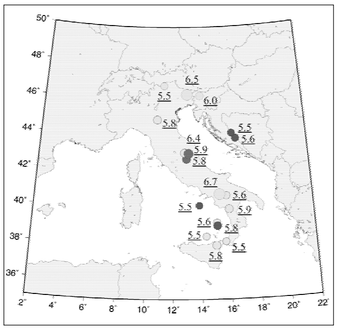
Monitored region

Alerted region

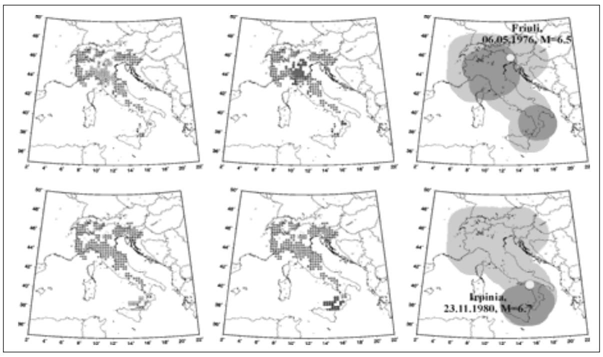
Predictions as on: 1-7-2009

M8S retrospective results for Italy (1972-2001)

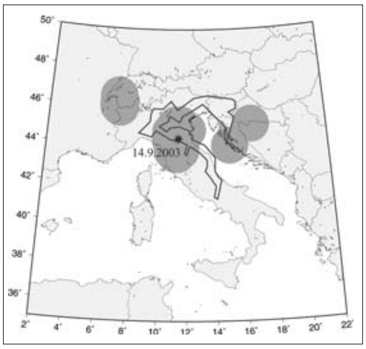
Strong earthquakes			Space-time volume of alarm, %
M_0	All	Predicted	
6.5	2	2	36
6.0	2	1	40
5.5	14	9	39



Scheme of M8S algorithm prediction of earthquakes Friuli, 06.05.1976 and Irpinia, 23.11.1980.



Integrating CN and M8s prediction results



- **5 out of the 8 events with M ≥5.5, common to the 2 experiments (CN and M8s), are predicted by alarms declared by both algorithms.**
- **Space-time volume occupied by alarms around 16%.**
- **Space uncertainty reduced to about 15% of the common monitored area.**

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).

The real-time earthquake prediction experiment in Italy

Intermediate-term middle-range earthquake prediction experiment in Italy

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 prediction experiment started in July 2003
(*Peresan al., Earth Sci. Rev. 2005*).

Intermediate-term middle-range earthquake prediction experiment in Italy

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

Updated predictions are regularly posted at:

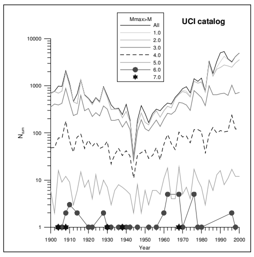
"http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm"

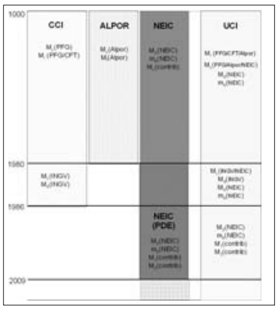
A complete archive of predictions is made accessible to a number of scientists, with the goal to accumulate a collection of correct and wrong predictions, that will permit to validate the considered methodology.

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.

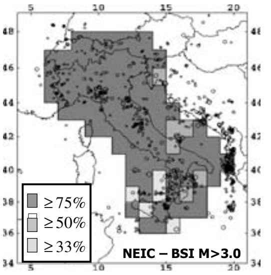


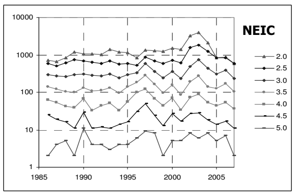


- Italian catalog (basically PFG and Alpor data) is used up to 1985, mainly to set up the algorithms parameters
- Global data from NEIC are used since 1986 to perform routine real time predictions

Analysis of spatial completeness of global catalog NEIC for the territory of Italy

The analysis is carried out according to *Kossobokov et. al., 1999*. The Bollettino Sismico Italiano, BSI catalog, since 16 April 2005 to 1 January 2008 is used as reference data set ⇒ The level of reporting for M ≥3.0 events in NEIC is comparable (76-100%) with that of BSI for most of Italy in the period 2005-2007.





It is also found that the level of detection of magnitude 3.0 and even 2.5 earthquakes in NEIC catalog keeps rather stable in the period 1986-2007

L.Romashkova, lina@mitp.ru

Values of the ratio (n/N) for 1 by 1 degree cells over the territory of Italy. Empty cells correspond to the cells with no earthquakes registered in the BSI, and for the cells outside the territory of M=3.0 completeness of the BSI catalog.

latitude

longitude	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
49.00														
48.00			100		100		100							
47.00	100				100		100	100	100					
46.00	100	100	100	100	100	100		100	67					
45.00	100	100	100	100	92	100	100	100						
44.00		100			100	100	100	100		100				
43.00							100	94		75	63	100		
42.00							100	100	100	71	100			
41.00							100	100	78	100			100	
40.00							100	100	50	85	81	71		
39.00							50	82	45	76	67	100		
38.00								33	85	80	100			
37.00								100	100	50				

The level of reporting of earthquakes with magnitude 3.0 and above in NEIC in 2005-2007 is comparable (76-100%) with that in the BSI for the greater part of Italy. Some decrease of completeness is observed for small areas east of Istria, Gargano and offshore, and south-east Calabria (63-75%). The worse recordings are around Sicily and deep earthquakes in the Tyrrhenian Sea (33-50%).

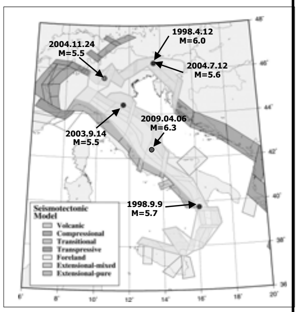
L.Romashkova, lina@mitp.ru

The CN real-time monitoring of seismic flow

Real-time testing 1998-2009

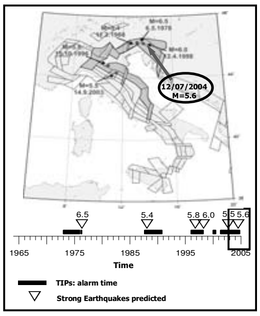
Earthquakes occurred within the space-time-magnitude volume monitored by CN since 1998

Date	Latitude, °N	Longitude, °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



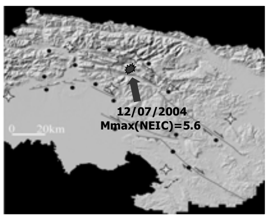
Updated to September 1 2009 (next updating November 1 2009)

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)

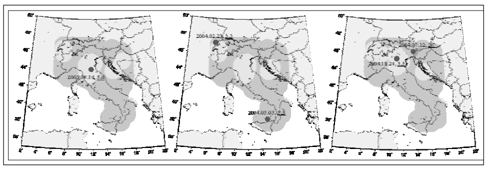
Southeastern Alps – External Dinarides
InSAR - CGPS - Campaign GPS monitoring



The M8S real-time monitoring of seismic flow

Real-time testing M5.5+, 2002-2008

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
2004.11.24	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

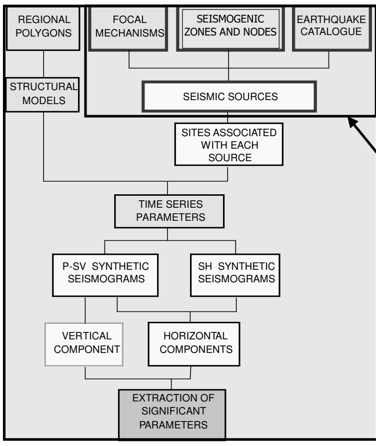
Events with M_{max} ≥5.5 occurred since July 2003

Updated to January 1 2009

Time dependent Neo-deterministic Hazard Scenarios

Regional seismic hazard scenarios
(ground motion at bedrock)

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



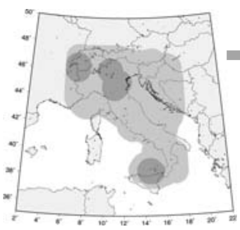
Flow-chart of the neo-deterministic hazard method

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.

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

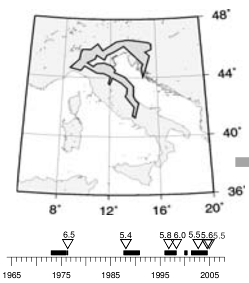
Prediction of earthquakes with M5.5+

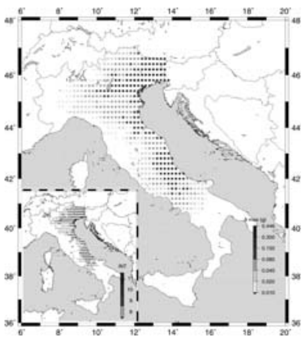


Alerted areas by M8S algorithm for an earthquake with 5.5≤M<6.0 (as on 1 July 2006 – 1 January 2007)

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

Northern Region
Prediction of earthquakes with M≥5.4





The Aquilano earthquake 6th April 2009

The Aquilano earthquake, 6th April 2009

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

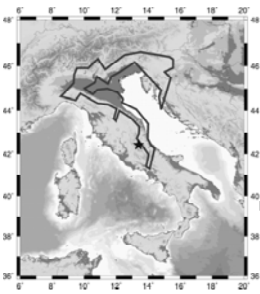
CN Algorithm

- 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)

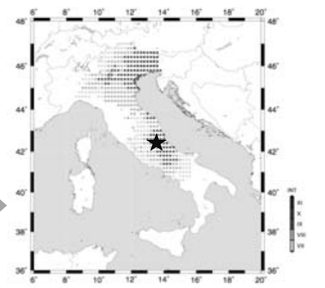
M8S Algorithm

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

The Aquilano earthquake, 6th April 2009

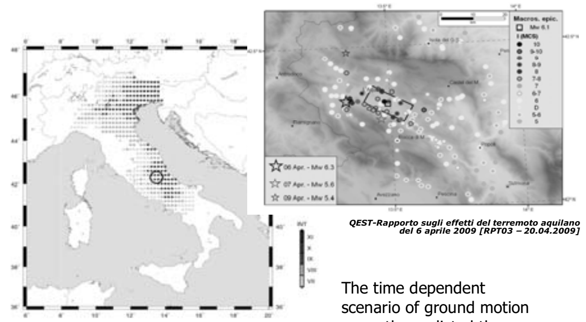


Alarmed polygon (red line) identified by CN algorithm for the period 1 March 2009 – 1 May 2009. The star indicates the epicenter of the 6 April 2009 event.



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 blue star

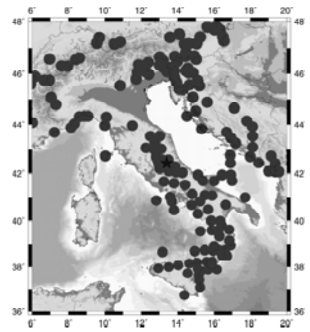
The Aquilano earthquake, 6th April 2009



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

The time dependent scenario of ground motion correctly predicted the occurred Intensities

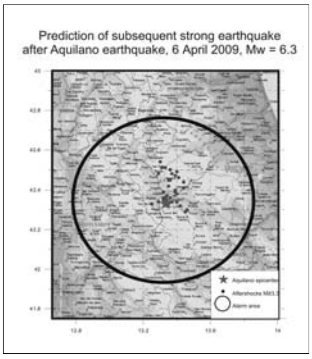
The recent Aquilano earthquake, 6th April 2009



Nodes prone to earthquakes with M≥6.0. The star indicates the position of the event of April 6, 2009.

Gorshkov, Panza, Soloviev, Aoudia (2004) - Boll. Soc. Geol. It., 123, 3-18.

Prediction of Subsequent Strong Earthquake in Central Italy



The Aquilano earthquake
6 April 2009
Alarmed area for M≥5.3
by SSE algorithm

Application of the algorithm SSE *(Vorobieva, 1999; Vorobieva and Panza, 1993)* to the aftershocks of this earthquake leads to the following prediction: a subsequent strong earthquake with magnitude M ≥ 5.3 is expected within 43 km of the epicenter of the Aquilano earthquake (for details see http://www.mitp.ru/en/restricted_global/Aquila16.gif).

The algorithm is applied using the preliminary data from NEIC and INGV.

Vorobieva@mitp.ru
www.mitp.ru
http://www.mitp.ru/en/sse/SSE-Alg.html

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 (2002-2009)	35	0/0	39	0/1	20	5/9
All together (1972-2009)	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 July 1 2009; next updating January 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 – 2009)	27	4/6	95
All together (1954 – 2009)	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 September 1 2009; next updating November 1 2009)

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

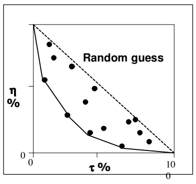
Intermediate-term middle-range earthquake prediction

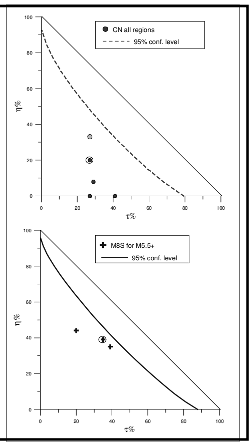
Evaluation of prediction results

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 September 1 2009

(next updating November 1 2009)

Evaluation of prediction results: CSEP Testing in Italy

Goals of the Collaboratory for the Study of Earthquake Predictability (CSEP): the testing Center at SCEC is designed to provide an well controlled environment in which earthquake forecasts can be run and evaluated over a substantial period of time.

Goals and requirements:

1. **Establish rigorous methods for registering prediction procedures.**
2. **Develop community-endorsed standards for assessing probability-based and alarm-based predictions.**
3. **Develop hardware and software support that would allow individual researchers and groups to participate in prediction experiments; and update their procedures as results become available.**
4. **Provide prediction experiments with access to data and monitoring products, authorized by the agencies that produce them.**
5. **Accommodate a wide-ranging set of prediction experiments involving fault systems in different geologic environments.**

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

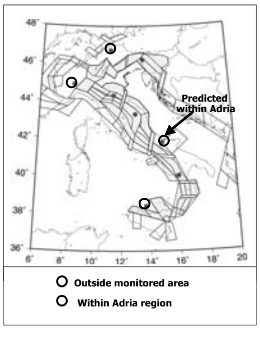
1. **Errors in the input data.** ***"Models will be evaluated against the authoritative observed data supplied by INGV […]. The INGV ML magnitude scale will be considered the reference scale for model development and testing."***
2. **Missing methods/criteria to compare different alarm-based models and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

Evaluation of prediction results: examples of biased assessment

Some possible pitfalls in the analysis of prediction models (e.g. *Marzocchi, Annals of Geophys, 2008*)

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**

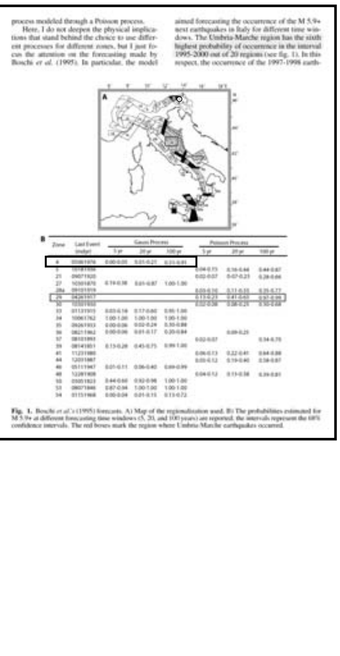
No systematic formal analysis of prediction results



Evaluation of prediction results: examples of biased assessments

Neglecting evident failures creates the impression of high efficiency…

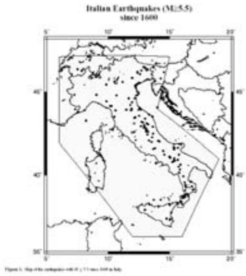
Bovec 1998 event (M=6.0) is inside Zone 4 that has the 2nd smallest probability in Table after Boschi et al. (1995).


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-

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.

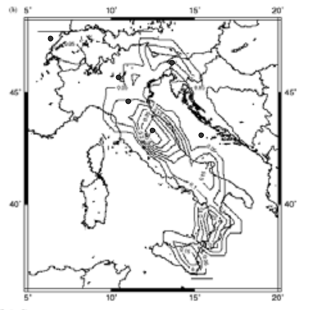
Marzocchi (Annals of Geophys, 2008)



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**

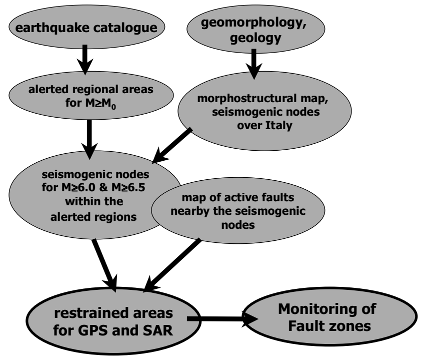


Evaluation of the space-time volume of alarm is also necessary…

(Faenza, Marzocchi & Boschi, GJI 2003)

Work in progress…

Integration with geodetic observations



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.

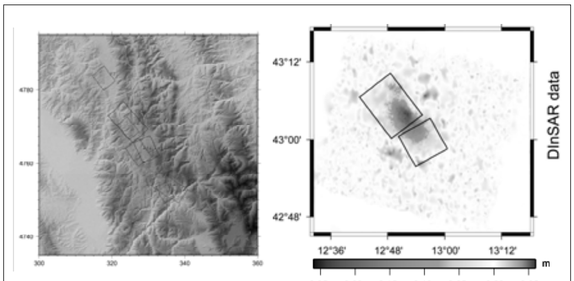
Routinely updated CN and M8S predictions are made available to the Civil Defence of the Friuli Venezia Giulia Region (NE Italy)

agenzia spaziale italiana · DST · University of Milano · Politecnico di Milano · galileian

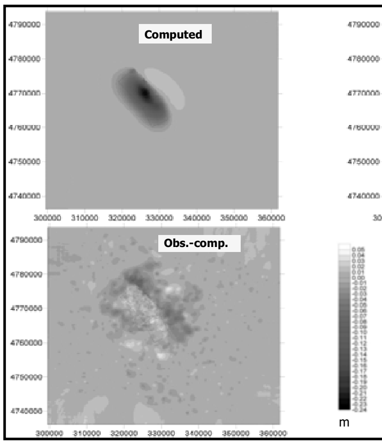
SISMA Overall Description

- **Maps of alerted areas, prone to earthquake events with given magnitude, will be obtained through comparison of non-EO information, provided by seismological data analysis, and taking into account results provided by Geophysical Modelling based on EO information;**
- **EO observations, consisting of GPS and DinSAR images, will permit to draw deformation maps on the surface;**
- **Stress maps at the depth of the active faults will be obtained through integration of EO geodetic information into Geophysical Forward Modelling.**

Methodology for detecting the vertical movements during the pre-seismic, co-seismic and post-seismic phases in earthquake prone areas



Colfiorito seismic sequence 1997



Comparison between predicted crust and lithosphere deformation patterns and SAR retrieved ones show the feasibility of contribution to seismic hazard assessment by means of the synergic use of InSAR and geophysical modeling.

Conclusions

- **Fully formalized algorithms for intermediate-term middle range earthquake predictions are currently available for the routine monitoring of seismicity. The real-time monitoring of seismic flow allows for the forward testing of CN and M8S predictions.**
- **Pattern recognition techniques, developed for the space-time identification of impending earthquakes, contribute to the definition of a set of time-dependent neo-deterministic scenarios of ground motion at regional and local scale.**
- **One of the advantages of the proposed approach consists in the time information provided by intermediate-term predictions, that supply decision makers an objective tool indicating priorities for timely mitigation actions (e.g. retrofitting of critical structures).**