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Prospective testing of intermediate-term middle-range earthquake predictions in Italy

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ICTP Advanced School on
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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.

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

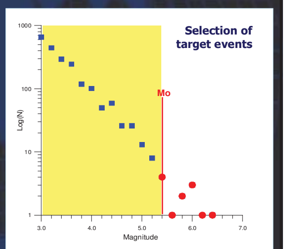
Normalization is necessary to ensure uniform application with the same set of adjustable parameters in regions of different seismic activity.

CN algorithm in Italy

Rules for CN application and selection of target events

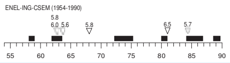
- **Area:** 5L-10L (L is the source linear dimension)
- **Magnitude of completeness**:
  - Yearly average number of events with $M \geq M_c$ must be>3
  - $M_o - \Delta M \geq M_c$ where $\Delta M \approx 3$
- **Selection of target events: Magnitude threshold M_o**
  - The return period for events with $M \geq M_o$, 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.

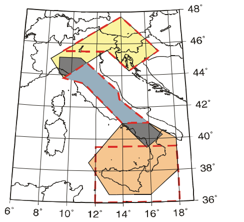


Evolution of CN regionalization for the Italian territory

- TSP:1954-1986; TIP diagnosis: 1954-1990
- 80% predicted events (4 out of 5)
- TIP: 26.0% of total time



(Keilis-Borok et al., 1990)



	NORTH		CENTRE		SOUTH	
	Area 1	Area 2	Area 1	Area 2	Area 1	Area 2
Events Predicted/total	2/2	2/2	3/3	3/4	3/3	1/2
False alarms	1	2	2	4	5	2
TIP %	27	34	23	38	33	25

(Costa et al., 1995; 1996)

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

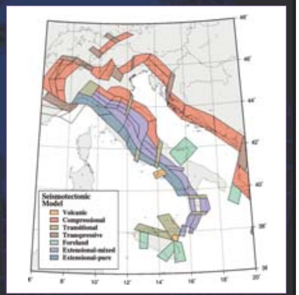
A single region includes:

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:

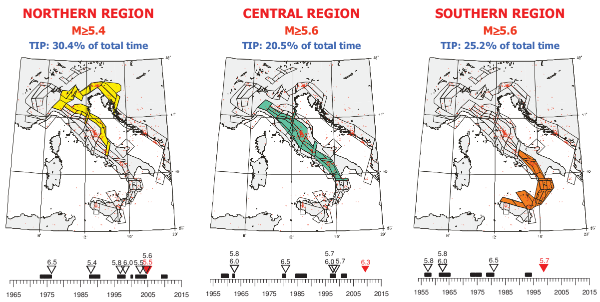
1. **it is between zones of the same kind;**
2. **it is at the edges of the region and the space distribution of the aftershocks reveals a possible connection.**

(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

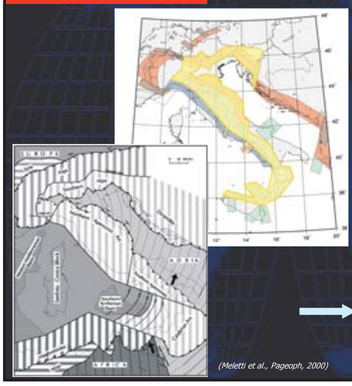


Predictions regularly updated since 1998

The regionalization based on the seismotectonic model

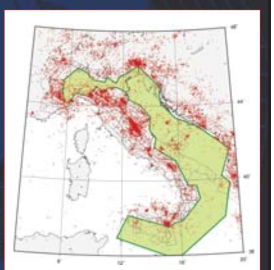
- **The seismotectonic model, supported by kinematic arguments, can be viewed as a useful tool that permits to optimise the selection of the fault systems involved in the generation of strong earthquakes.**

Adriatic Region



(Meletti et al., Pageoph, 2000)

CN region



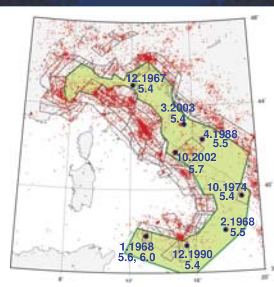
CN application to the Adriatic region

ADRIA REGION

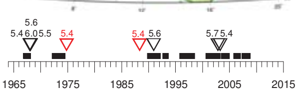
Prediction of the events with M≥5.4

TSP: 1964 – 1999
Predictions regularly updated since January 2003

78% predicted events (7 out of 9)
TIP: 34.2% of total time
6 false alarms



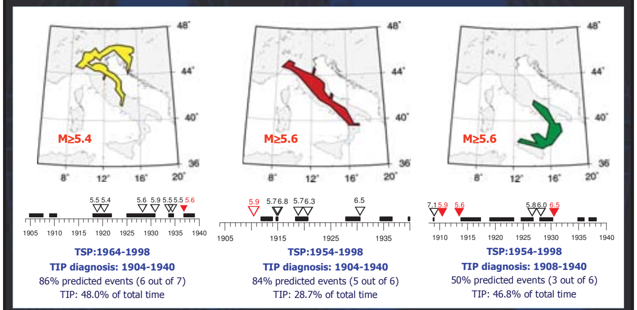
TIPs
Strong Earthquakes predicted
Failure to predict



CN algorithm in Italy: stability experiments

Algorithm CN in Italy: stability experiments

"Seismic history" experiment



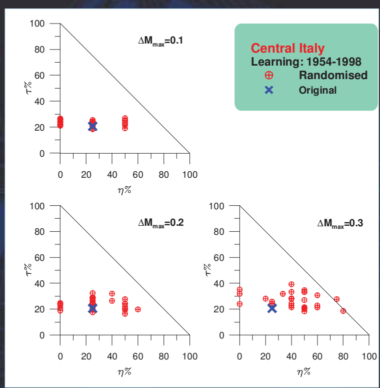
Peresan, Vaccari, Romanelli, Panza (2005) - Atti dei Convegni Lincei. 218, 263-287.

Stability of TIPs diagnosis with respect to random errors in magnitude

Central Italy

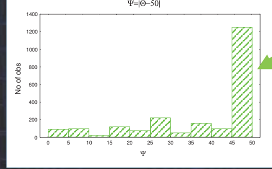
$\eta = n/N$: the rate of failures-to-predict

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

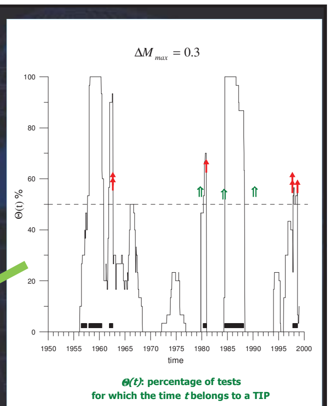


Stability of TIPs diagnosis with respect to random errors in magnitude

Central Italy



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: $M_0 \le M \le M_0+0.5$).

Algorithm M8S

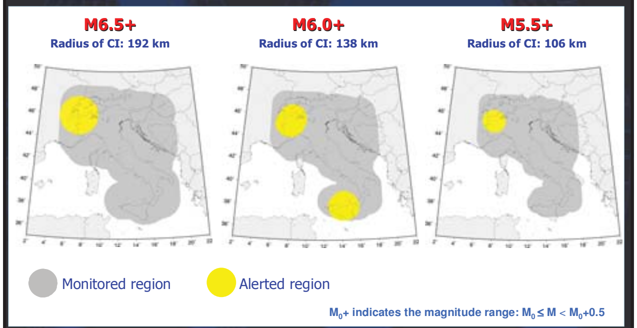
▪A spatially stabilized variant of the algorithm M8 has been proposed , namely M8S algorithm, where the seismicity is analysed within a dense set of overlapping circles covering the monitored area (*Kossobokov et al., JSEE 2002*).

▪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

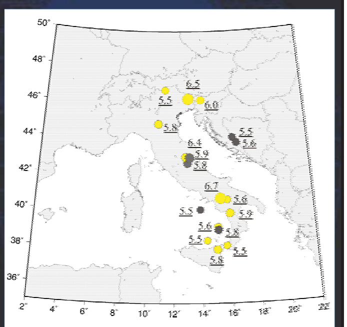
1. The seismically active grid points are then selected by the condition that the average annual rate of seismic activity, within the small circle, is above a given threshold.
2. The grid points where data are insufficient for the application of M8 algorithm and isolated grid points are excluded.
3. 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

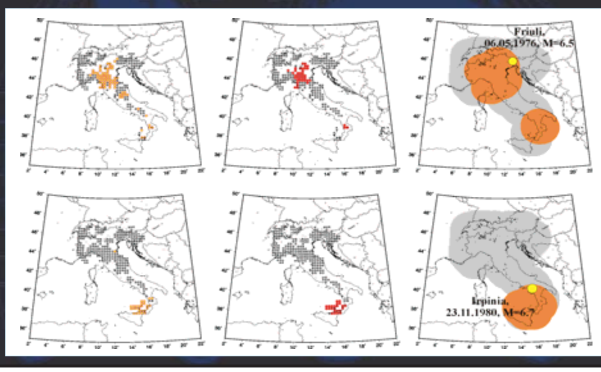


M8S retrospective results for Italy (1972-2001)

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.



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

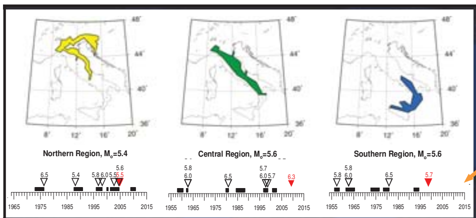
The prediction experiment, ongoing for more than eight years, is aimed at a *real-time test* of CN and M8S predictions in Italy.

Updated predictions are regularly posted at:

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

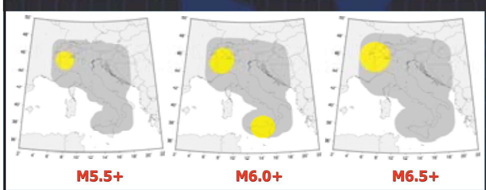
A complete archive of predictions is made accessible to a number of scientists, with the goal to accumulate a collection of correct and wrong predictions, that will permit to validate the considered methodology.

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 algorithm

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



M8S algorithm

Monitored region

Alerted region

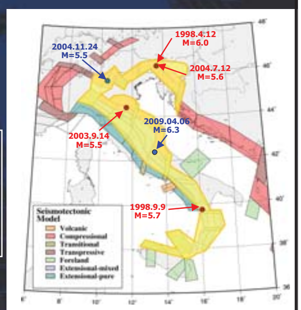
(*Peresan al., Earth Sci. Rev. 2005*)

The CN real-time monitoring of seismic flow

Real-time testing 1998-2011

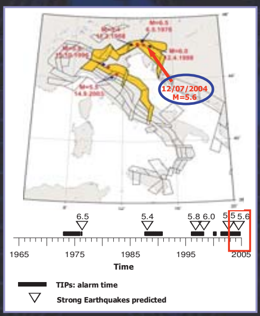
Earthquakes occurred within the space-time-magnitude volume monitored by CN since 1998

Date	Latitude, °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 September 1 2011 (next updating November 1 2011)

The CN real-time monitoring of seismic flow



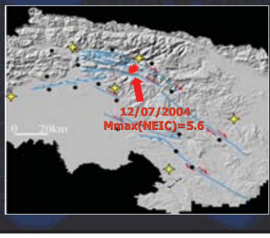
The Bovec earthquake - July 12 2004

Alarmed area for M≥5.4 by CN algorithm

(Peresan et al., ESR,2005)

(As on 1 July 2004)

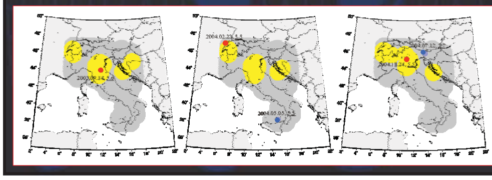
Southeastern Alps – External Dinarides
InSAR - CGPS - Campaign GPS monitoring



The M8S real-time monitoring of seismic flow

Real-time testing M5.5+, 2002-2011

Date	Latitude, ^{0}N	Longitude, ^{0}E	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} ≥5.5 occurred since July 2003

Updated to July 1 2011

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	39	1/2	39	9/14
Forward (2002-2011)	30	0/0	35	0/1	17	5/9
All together (1972-2011)	35	2/2	38	1/3	34	14/23

Algorithm M8s predicted 63% of the events occurred in the monitored zones in Italy, i.e. 17 out of 27 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 2011;
Next updating January 2012)

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 – 2011)	28	4/6	95
All together (1954 – 2011)	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 2011;
Next updating November 2011)

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

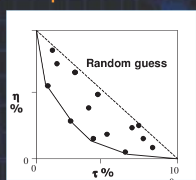
Intermediate-term middle-range earthquake prediction

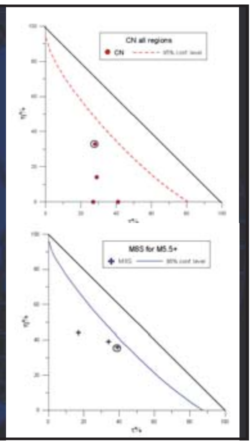
Evaluation of prediction results

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

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

τ : the space-time volume of alarm





CN and M8S predictions in Italy

Updated to July 1 2011 (next updating January 1 2012)

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.

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

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

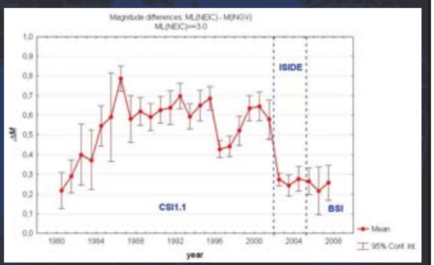
1. **Errors in the input data.** *"Models will be evaluated against the authoritative observed data supplied by INGV [...]. The INGV ML magnitude scale will be considered the reference scale for model development and testing."*
2. **Missing methods/criteria to compare** different alarm-based models and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

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) difference is well comparable to that evidenced so far by *(Peresan, Panza & Costa, GJI 2000).*

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

Evaluation of prediction results: examples of biased assessment

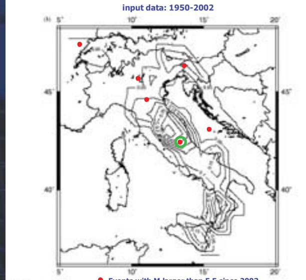
Some possible pitfalls in the analysis of prediction models (e.g. *Marzocchi, Annals of Geophys, 2008)*

1. Comparison of statistics achieved in real-time time testing to the model ones, with parameters adjusted a posteriori.
2. Neglecting evident failures allows to create the illusion of high efficiency for some other models
3. Evaluation of the space-time volume of alarms is also necessary…

⇒ **No systematic formal analysis of prediction results!**

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

(Faenza, Marzocchi & Boschi, GJI 2003)

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).

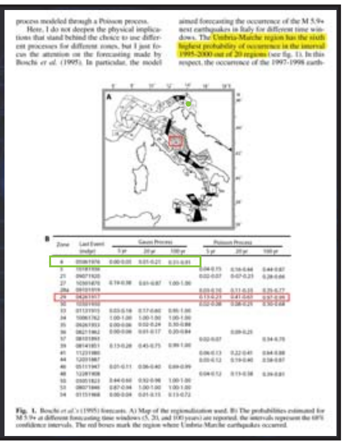

process modeled through a Poisson process. Here, I do not deepen the physical implications that stand behind the choice to use different processes for different zones, but I just focus the attention on the forecasting made by Boschi et al. (1995). In particular, the model aimed forecasting the occurrence 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)

Evaluation of prediction results: the ICEF report

Report by the International Commission on Earthquake Forecasting

"A prediction is defined as a deterministic statement that a future earthquake will or will not occur in a particular geographic region, time window, and magnitude range, whereas a forecast gives a probability (greater than zero but less than one) that such an event will occur."(page 319)

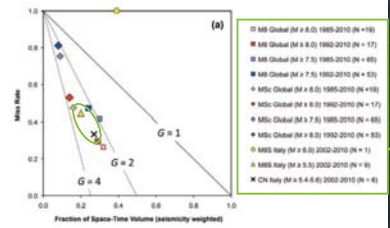
"Alert procedures should be standardized to facilitate decisions at different levels of government and among the public. Earthquake probability thresholds should be established to guide alert levels based, when feasible, on objective analysis of costs and benefits." (page 359) ⇒ This turns forecasts into predictions…

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

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: the ICEF report

"Need for Probabilistic Earthquake Forecasting

*The public needs information about future earthquakes. However, earthquake generation is a very complex process occurring in an underground environment that is very difficult to observe. Given the current state of scientific knowledge, individual large earthquakes cannot be reliably predicted in future intervals of years or less. In other words, **reliable and skillful deterministic earthquake prediction is not yet possible.***

***Any information about the future occurrence of earthquakes** contains large uncertainties and, therefore, **can only be evaluated and provided in terms of probabilities**. Probabilistic earthquake forecasting can convey information about future earthquake occurrence on various time scales, ranging from long term (years to decades) to short term (months or less). Probabilistic forecasting is a rapidly evolving field of earthquake science." (page 360)*

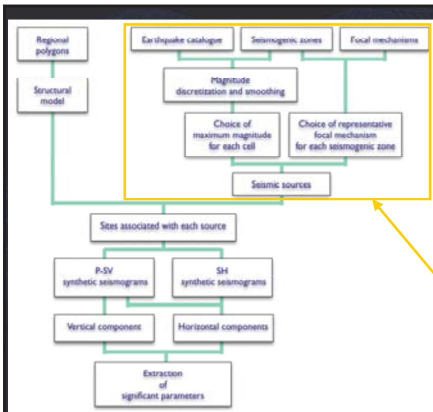
⇒ There is no validated probabilistic model forecasting large earthquakes yet…

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

Time dependent Neo-deterministic Hazard Scenarios

Regional seismic hazard scenarios
(ground motion at bedrock)

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

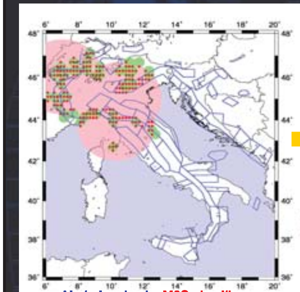


Time-dependent Seismic Hazard Scenarios

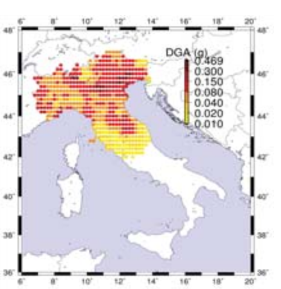
Regional ground shaking scenarios associated with alerted regions
(ground motion at bedrock)

Seismic sources (defined based on seismic history, seismotectonic and morphostructural nodes) are selected within the **alerted regions**.

Time-dependent Neo-deterministic scenarios
(associated to the alerted regions)



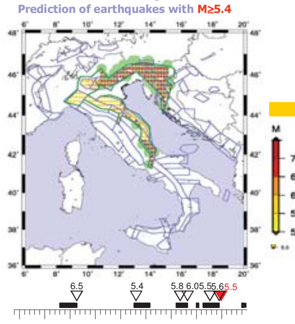
Alerted region by M8S algorithm
for an earthquake with 6.5≤M<7.0
(pink area: alarmed territory; green circles: seismogenic nodes; blue polygons: seismogenic zones; dots: sources considered for the scenario computation)

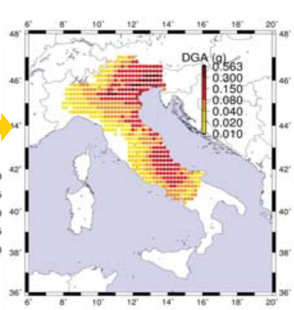


Ground shaking scenario
Design ground acceleration for all the possible sources included in the alerted region

Neo-deterministic scenarios associated to alerted regions: CN algorithm

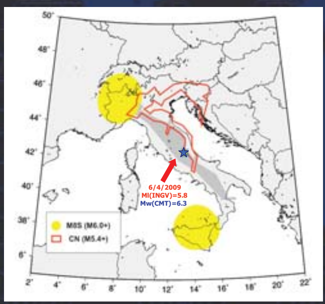
Northern Region
Prediction of earthquakes with M≥5.4





Ground shaking scenario
(design ground acceleration)

The Aquilano earthquake, 6th April 2009



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

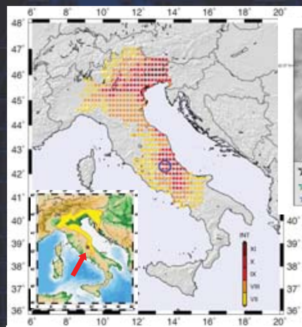
CN Algorithm

- 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)

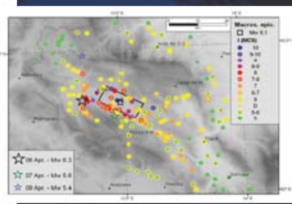
M8S Algorithm

- 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

Integrating data from Earth-Observation: the ASI-SISMA project

Department of Geosciences · University of Milano · Politecnico di Milano · galileian

ASI Pilot Project - SISMA

"Seismic Information System for Monitoring and Alert"

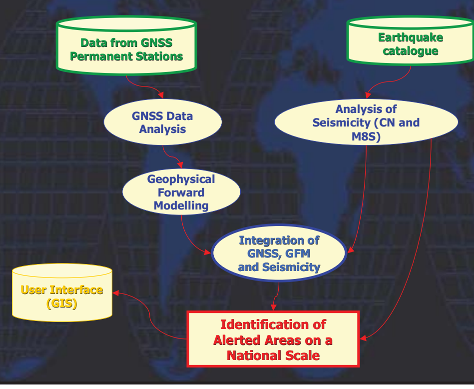
Development of a fully formalized system for the time dependent neo-deterministic definition of seismic hazard, integrating the space and time information provided by real-time monitoring of seismic flow and Earth Observation (GNSS, SAR) data analysis, through geophysical forward modeling.

➡ **Operational approach: routinely updated information on alerted areas, as well as the related hazard maps, are made available to the Civil Defence of the Friuli Venezia Giulia Region (NE Italy) using a GIS interface.**

EO data and Geophysical modeling

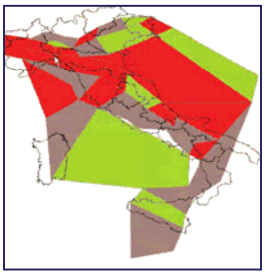
- **Maps of alerted areas at the national scale, are obtained by the synergic use of space-time information provided by seismological data analysis, and Geophysical modeling based on EO information.**
- **At the local scale (tens of km) EO observations, consisting of GPS and DinSAR images, permit to retrieve the deformation style and stress evolution and to draw deformation maps on the surface.**
- **Stress maps at the depth of the active faults are obtained through integration of EO geodetic information into Geophysical Forward modeling, which permits to indicate whether a specific fault is in a "critical state".**

SISMA: National scale alert

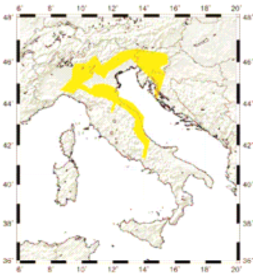


Alerted Areas at National scale

Integrating information from GNSS anomalies identified at national scale and alerted areas identified by the pattern recognition analysis of seismicity



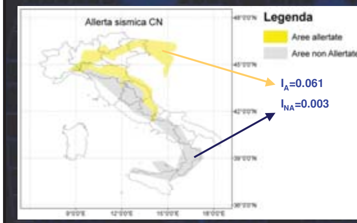
Map of GNSS anomalies
(red: anomaly; green: no anomaly; gray: no data)



Alerted area based on seismicity analysis
(yellow: CN northern region)

Alerted Areas at National scale

Characterization of alarms by CN and M8S algorithms, aimed at integration with information about geodetic anomalies.



Indicators for A and NA:

$$I_A = \frac{stv(true-alarms)}{stv(all-alarms)}$$

$$I_{NA} = \frac{stv(false-no-alarms)}{stv(all-no-alarms)}$$

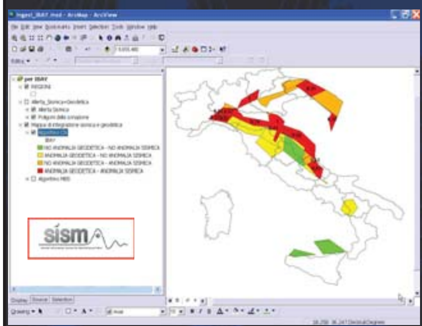
$$stv(A) = \frac{\int_A d(t\times r)}{\int_{T\times R} d(t\times r)}$$

T total time of analysis
R total space of analysis
$t\times r$ is a measure over $T\times R$

Indicators provide an integral estimate of the rate of confirmed alarms and failures to predict, as obtained over the whole monitored territory.

Alerted Areas at National scale

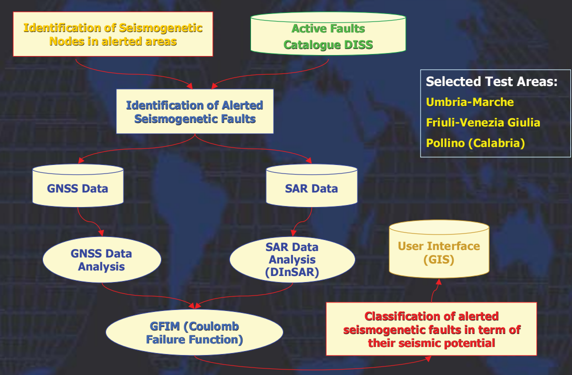
Integrated map of alerted areas



- **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**

http://sisma.galileianplus.it/

SISMA: Local scale alert



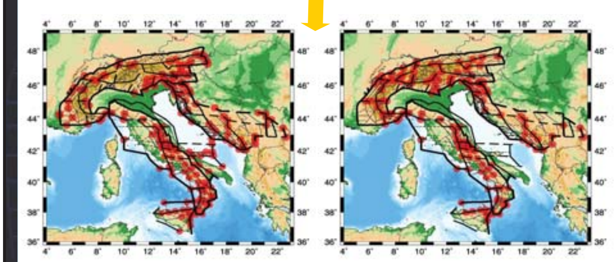
Selected Test Areas:
Umbria-Marche
Friuli-Venezia Giulia
Pollino (Calabria)

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.**

Seismogenic nodes

Morphostructural zonation + pattern recognition

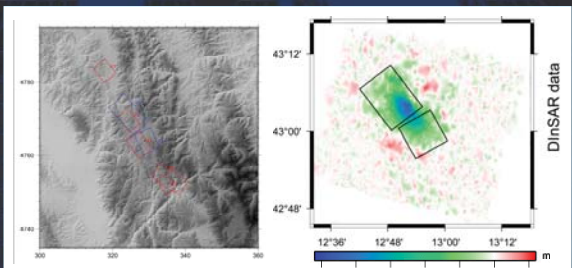


M≥6.0 **M≥6.5**

Morphostructural zonation (in black) and seismogenic nodes (red circles) identified for the Italian territory and surrounding regions
(Gorshkov et al., 2002; 2004)

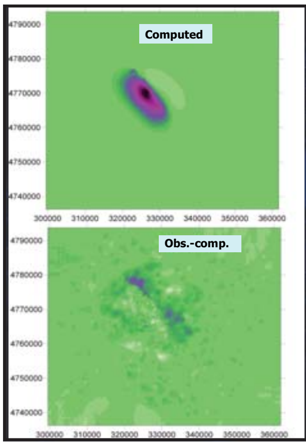
EO data and Geophysical modeling

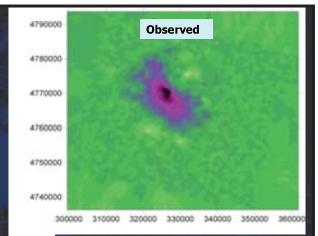
Methodology for analysis of the vertical movements
during the pre-seismic, co-seismic and post-seismic phases



Colfiorito seismic sequence 1997

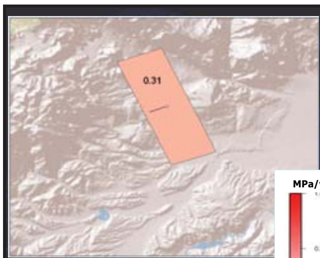
Dalla Via et al., GRL, 34, (2007)





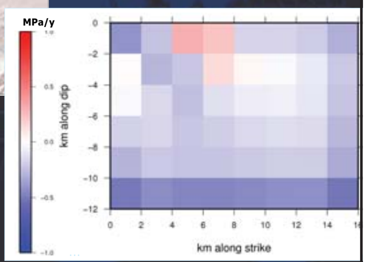
Comparison between predicted crust and lithosphere deformation patterns and SAR retrieved ones show the feasibility of contribution to seismic hazard assessment by means of the synergic use of InSAR and geophysical modeling.

Dalla Via et al., GRL, 34, (2007)



Pollino area (Southern Italy): fault from DISS database

Modelled variations of Coulomb Failure Function (CFF) along fault plane



Positive variations of CFF are favourable to fracture

Sabadini, Crippa, Dalla Via

Operational approach:

An Agreement has been signed among the Abdus Salam International Centre for Theoretical Physics, **ICTP**, and the **Civil Defence** of the Friuli Venezia Giulia Region (NE Italy) for the practical implementation of the integrated neo-deterministic hazard procedure.

Routinely updated CN and M8S predictions, as well as the related hazard maps, are made available to the Civil Defence of the Friuli Venezia Giulia Region since 2006.

The Abdus Salam International Centre for Theoretical Physics

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 rigorous prospective testing and validation of CN and M8S predictions.**
- **Earth Observation Data (SISMA system) and 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).**