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Experiments wtih Intermediate-term Medium-Range Earthquake Prediction Algorithms in Italy and Seismic Hazard

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Experiments with intermediate-term medium-range Earthquake prediction Algorithms in Italy and seismic hazard

- Introduction
- Earthquake precursors
- Premonitory seismicity patterns
- Earthquake prediction
- Algorithms M8 and CN
- Evaluation of prediction results
- Integrated deterministic hazard

INTRODUCTION

"Earthquakes' modelling involves a detailed knowledge of the related physics, which is not available at present time. [...] A firm and complete phenomenological picture should be established before any effort can result effective, but such a picture is not easy to draw due to the long time scales involved. [...] The analysis of seismicity patterns is useful not only for prediction purposes, but it provides also the wide set of systematic observations, without which any physically based model remains a merely theoretical speculation."

Earthquake prediction: the scientific challenge

(Knopoff, 1996)

Characteristics of the lithosphere

- Scale invariance of earthquake distribution in time and space
- Self-organization of earthquake occurence
- Non-linear mechanics of earthquake generation
- Statistical features of earthquake sequences

→ Strongly indicate that the lithosphere behaves as a **deterministic chaotic system** (Keilis-Borok, 1990).

How we can predict earthquakes?

Deterministic prediction?

NO

For complex or chaotic systems, even an accurate modelling would not allow for predictions.

Statistical prediction?

NO

Time scales involved in the seismogenic process are too long and observations too limited.

Possibility: **Identification of precursory phenomena.**

EARTHQUAKE PRECURSORS

Earthquake precursors

Possible precursors are those phenomena that may take place in the lithosphere during the accumulation of stresses.

Difficulty: to establish a clear precursory connection, i.e. to separate the precursory signal from natural fluctuations. This is due to the lack of sufficiently prolonged and systematic records.

"Signals" proposed as earthquake precursors

- Variations in the seismic activity
- Changes in the velocity and in the spectral content of seismic waves and earthquakes sources
- Crustal deformations and variations of the stress in the crust
- Gravitational, geomagnetic and geoelectrical precursors
- Anomalous changes in the underground water level and chemical components
- Anomalies in the atmospheric pressure, temperature and heat flow

IASPEI Preliminary List of Significant Precursors

Validation criteria for precursor candidates:

- the observed anomaly should be related to some mechanism leading to earthquakes;
- the anomaly should be simultaneously observed at more than one site or instrument;
- the definition of the anomaly and of the rules for its association with subsequent earthquakes should be precise;
- both anomaly and rules should be derived from an independent set of data, than the one for which the precursory anomaly is claimed.

IASPEI Preliminary List of Significant Precursors

Only five possible precursors, out of the forty proposed, seem to deserve further study *(Wyss, 1997)*:

- one based on ground water chemistry,
- one on crustal deformation and
- three on seismicity patterns

PREMONITORY SEISMICITY PATTERNS

Premonitory seismicity patterns

Some changes are observed in the earthquake's flow before a large event.

These changes are akin to the general symptoms of instability of many non-linear systems before a catastrophe (*Keilis-Borok, 1996*).

In particular, the response to a perturbation:

- increases,
- becomes more chaotic and
- acts at long distances.

Premonitory seismicity patterns

- In the case of seismicity the non-linear system is the hierarchical structure made up by the lithospheric blocks and by their boundaries (i.e. faults).
- The large earthquake is a catastrophic event, corresponding to abrupt changes of the system characteristics, that may involve a large domain of the system.
- The small earthquakes may be regarded as sources of perturbation of the system.

Premonitory seismicity patterns

Thus, before a strong earthquake, which represents the collapse of the system, we must observe:

- increase of the seismic activity, clustering of the earthquakes in time and space, and spatial concentration of sources; in other words, the increase of the response to the perturbation;
- increase of the variation of seismicity and its clustering, which reflects the chaotic response to the perturbation;
- long-range interaction of earthquakes, which can be interpreted as an increase of the range of influence of the perturbation.

Single seismicity patterns formally defined as premonitory

- **the *burst of aftershocks*** *(Keilis-Borok et al., 1980; Molchan et al., 1990)*, **which is associated to moderate magnitude events characterised by a large number of aftershocks;**
- **the *seismic quiescence*** *(Wyss et al., 1992)*;
- **the relative increase of the *b-value* for the moderate events, with respect to smaller events** *(Narkunskaya and Shnirman, 1994)*;
- **the increase of the *spatial correlation* in the earthquake flow and the log-periodic variations of the earthquake flow on the background of its exponential *rise*** *(Bufe et al., 1994)*.

Multiple seismicity patterns formally defined as premonitory

- **M8** (*Keilis-Borok and Kossobokov, 1987; Kossobokov et al., 1999*)
- **CN** (*Gabrielov et al., 1986; Keilis-Borok and Rotwain, 1990; Rotwain and Novikova, 1999)*
- **Mendocino scenario** (*Kossobokov, Keilis-Borok, and Smith, 1990; Kossobokov et al., 1999*);
- **Next Strong Earthquake** (*Vorobieva, 1999*)

EARTHQUAKE PREDICTION

What does it means to predict an earthquake?

To predict an earthquake means to indicate the possibility that an earthquake will occur in a given range of

space
time
magnitude

What does it means to predict an earthquake?

- **The prediction can miss events or have false alarms, but forecasts must demonstrate more predictability than a random guess.**
- **The space-time-magnitude volume considered to declare the alarms should be appropriate to public needs, i.e. to enable the relevant authorities to prepare for an impending destructive earthquake.**

Space Scale of Prediction

Predictions	Territorial uncertainty
Exact	Earthquake Size (EqS)
Narrow - range	Two-three EqS
Medium - range	Five-ten EqS
Long - range	Up to 100 EqS

Time Scale of Prediction

Predictions	Alarm duration
Immediate	Few hours
Short term	Few days
Intermediate - term	Few years
Long - term	Decades

Medium-range Intermediate-term Prediction

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

Medium-range Intermediate-term Prediction

- **Time uncertainty:** few years
- **Space uncertainty:** hundreds Km

Allows:

- To increase preparedness and safety measures
- To define priority for detailed seismic risk studies
- Observation of possible short-term precursors (generally local)

Medium-range Intermediate-term Prediction

- A family of medium-range intermediate-term earthquake prediction algorithms has been developed, applying pattern recognition techniques, based on the identification of premonitory seismicity patterns.

Algorithms for Medium-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

Algorithms for Medium-range Intermediate-term Prediction

Algorithms globally tested for prediction are:

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

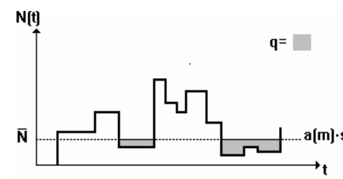
They allow to identify the TIPs (Times of Increased Probability) for the occurrence of a strong earthquake

Algorithms for Medium-range Intermediate-term Prediction

- The **algorithm MSc** (Mendocino Scenario, *Kossobokov, Keilis-Borok, and Smith, 1990; Kossobokov et al., 1999*) can be applied as a second approximation of M8. It allows us to reduce significantly the area of alarm (by a factor from 5 to 20).
- Independently, the **algorithm NSE** (Next Strong Earthquake, *Vorobieva, 1999*) is applied to predict a strong aftershock or a next main-shock in a sequence.

ALGORITHMS M8 AND CN

Functions of the seismic flow



$$q(t|\underline{M},s)=\sum_i\left[a(\underline{M})\cdot s-N(t_i|\underline{M},s)\right]$$

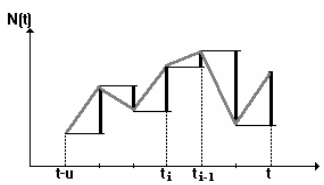
$a(\underline{M})$: is the the average yearly number of events

Quiescence

$$q(t|\underline{M},s)$$

corresponds to the sum of the grey areas for the time intervals (t-s,t) where the number of earthquakes is less than the average

Functions of the seismic flow



$$V(t|\underline{M},s,u)=\sum_i\left|N(t_i|\underline{M},s)-N(t_{i-1}|\underline{M},s)\right|$$

$i=1,\ldots,n \quad u=ns$

Variation of seismic activity

$$V(t|\underline{M},s,u)$$

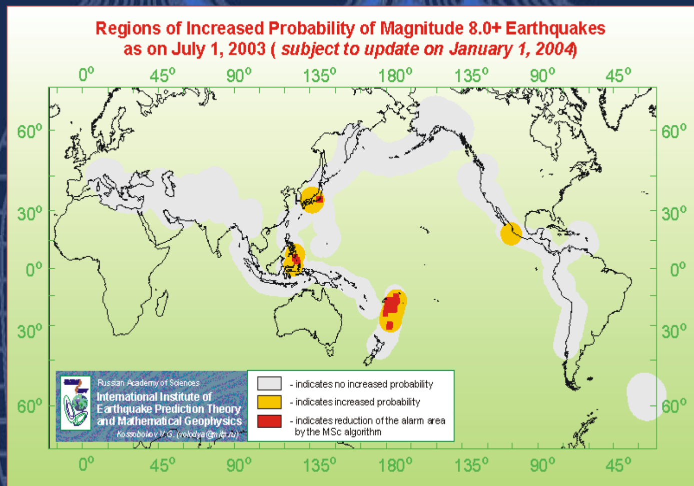
It is a measure of the cumulative changes in time of the earthquake number

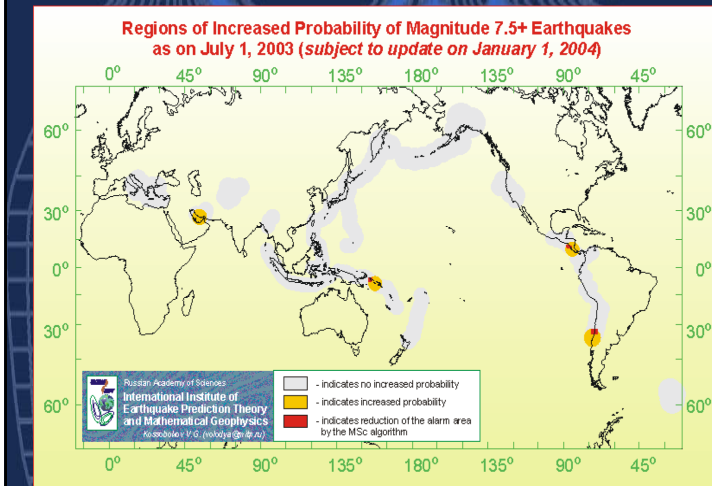
ALGORITHM M8

The algorithm M8 is applied on a global scale for the prediction of the strongest events:

Magnitude ≥ 8.0 Area: 667 Km radius

Magnitude ≥ 7.5 Area: 427 Km radius

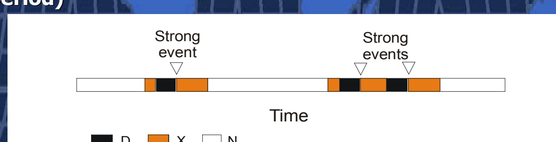




CN algorithm: the learning procedure

- **Fix Mo (average return period not lower than 6-7 years)**
- **Definition of the classes:**

- D: "dangerous" periods (2 years before each strong earthquake)
- N: "non dangerous" periods
- X: periods not classifiable as D or N
(3 years after a strong event + 1 year before each D period)



Definition of the discretization intervals and of the characteristic properties (X objects are excluded from this stage of the analysis)

CN algorithm: the recognition procedure

- **Selection of the objects for recognition with a fixed time step (2 months)**
- **Discretization and coding of functions**
- **TIPs diagnosis**

Algorithm CN

Area: 5L-10L (L is the source linear dimension)

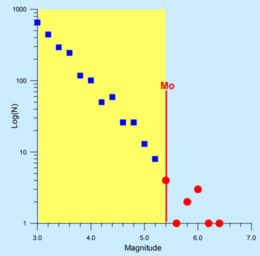
Magnitude:

$$M_0 - 3 \geq M_c$$

Yearly average number of events with magnitude above completeness must be > 3:

$$N(M \geq M_c) \geq 3$$

Choice of Mo



Return Period for events with M≥Mo not lower than 6-7 years

Performance of the algorithms

Algorithm	Regions considered	Strong earthquakes predicted/total	Time-space of alarms, %	Confidence level, %
M8	Circum Pacific, M □ 8 *	9/10	35	> 99
M8+MSc	"	7/10	18	> 99
CN	20 regions worldwide	16/21	24	95
NSE	Areas around 9 strong earthquakes worldwide	Predictions correct/wrong 25/4		97

* Prediction made within 170 overlapping circles of 1333-km diameter. The space-time volume has been determined by the most conservative measure that allows for various seismic activity of the territories.

Multiscale seismicity model and Algorithm CN

Gutenberg-Richter law

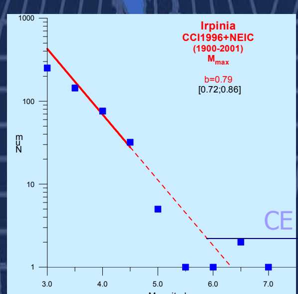
- The analysis of global seismicty shows that a single Gutenberg-Richter (GR) law is not universally valid and that a multiscale seismicity model can reconcile two apparently conflicting paradigms (Molchan et al., 1997):

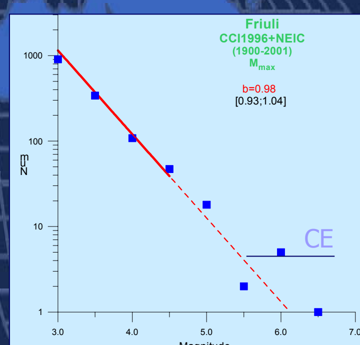
Gutenberg-Richter law

- Self-Organized Criticality (SOC) mechanism
- Characteristic Earthquake (CE) concept.

Self-organized criticality (SOC) is hypothesized to link the multitude of complex phenomena observed in Nature to simplistic physical laws and/or one underlying process. It is a theory of the internal interactions of large systems: large interactive systems will self-organize into a critical state - one governed by a power law. Once in this state, small perturbations result in chain reactions, which can affect any number of elements within the system. The Gutenberg-Richter magnitude-frequency relationship is the most commonly cited example of naturally occurring SOC phenomena.

The Gutenberg Richter law when applied to small parts of Italy (linear dimension 100-200 km) is linear only over a small magnitude interval [3-4.5].





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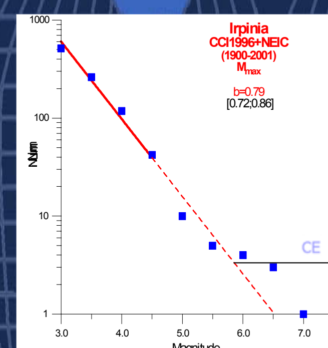
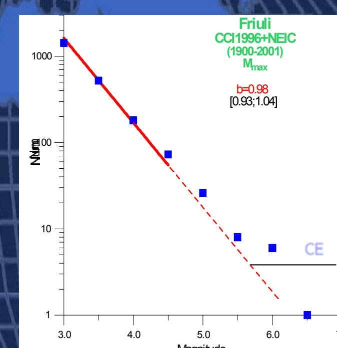
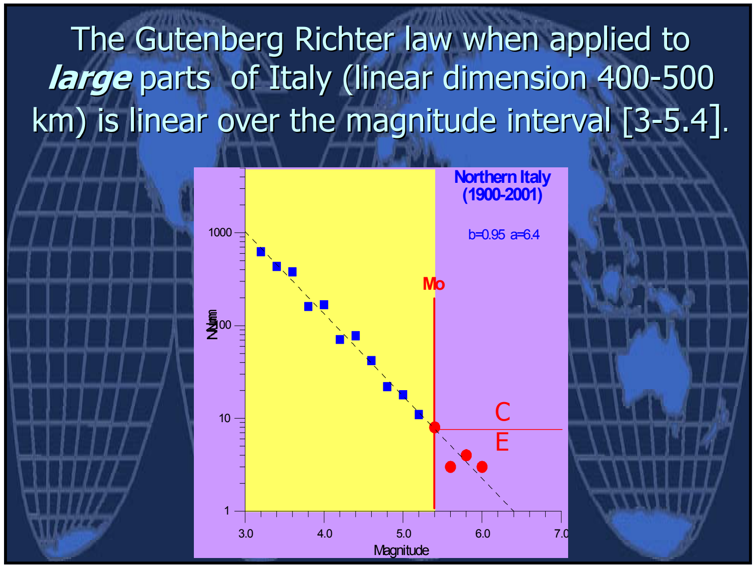
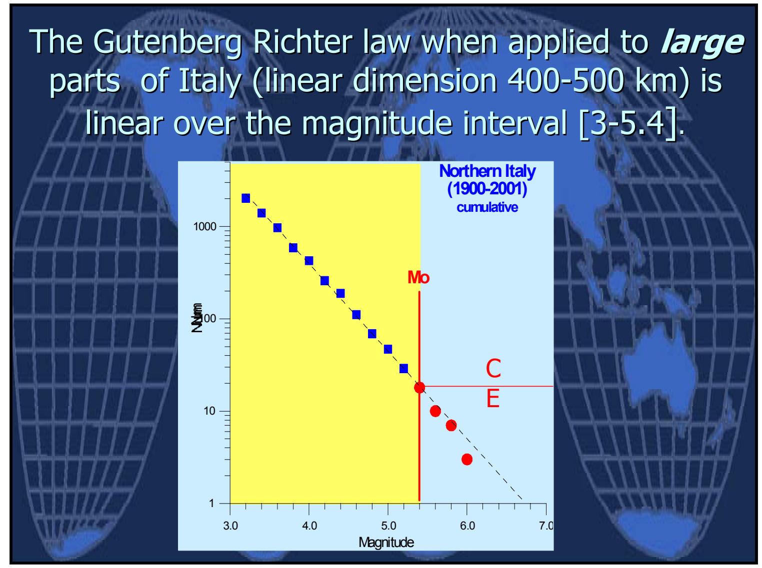




(cumulative)


The Gutenberg Richter law when applied to ***large*** parts of Italy (linear dimension 400-500 km) is linear over the magnitude interval [3-5.4].
Northern Italy (1900-2001)
b=0.95 a=6.4
Mo
C
E
N/year
1000
100
10
1
3.0
4.0
5.0
6.0
7.0
Magnitude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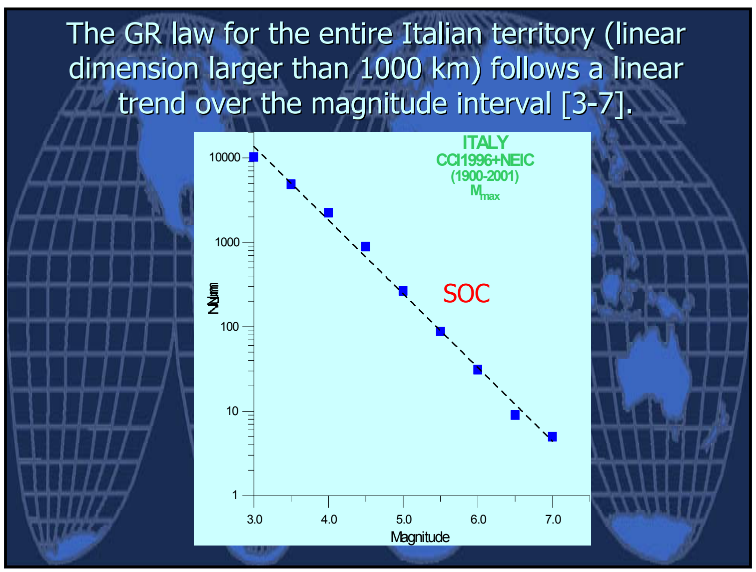
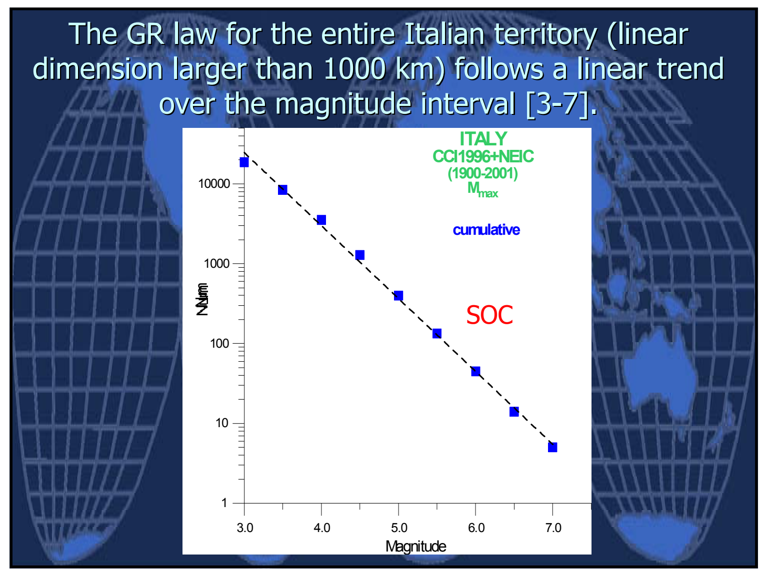
Northern Italy (1900-2001)
cumulative
Mo
C
E
N/year
1000
100
10
1
3.0
4.0
5.0
6.0
7.0
Magnitude


The GR law for the entire Italian territory (linear dimension larger than 1000 km) follows a linear trend over the magnitude interval [3-7].
ITALY
CCI1996+NEIC
(1900-2001)
M_{max}
SOC
N/year
10000
1000
100
10
1
3.0
4.0
5.0
6.0
7.0
Magnitude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ITALY
CCI1996+NEIC
(1900-2001)
M_{max}
cumulative
SOC
N/year
10000
1000
100
10
1
3.0
4.0
5.0
6.0
7.0
Magnitude

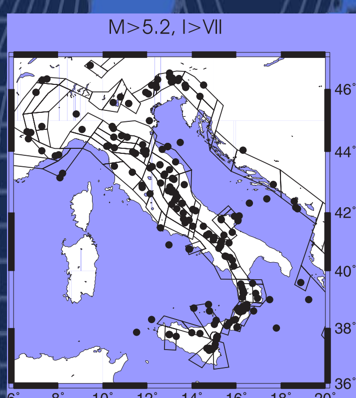
Gutenberg-Richter law

- The multiscale seismicity model, implies that only the set of earthquakes with dimensions that are small with respect to the elements of the zonation can be described adequately by the Gutenberg-Richter law.

Gutenberg-Richter law

- This conditon, fully satisfied in the study of global seismicity made by Gutenberg and Richter, has been violated in many subsequent investigations.
- Such a violation has given rise to the concept of Characteristic Earthquake (CE) in opposition to the Self-Organized Criticality (SOC) paradigm.

Gutenberg-Richter law

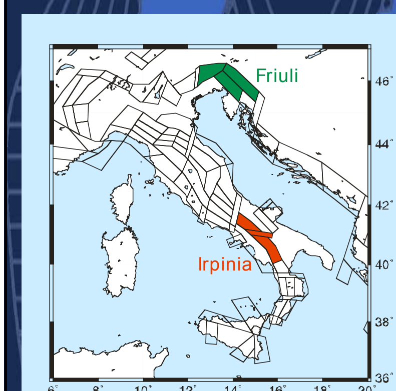


Seismogenic zone as defined by GNDT (Meletti et al., 2000).

For zones with characteristic dimensions of 200-300km (zones of level 1), i.e. 2-3 times larger then the maximum observed dimension for the areas covered by the aftershocks of the strongest main events (source dimensions), GR law is linear if M<4.5

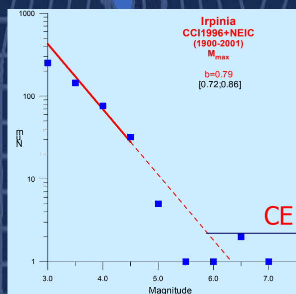
- main events in the period 1000-1980.

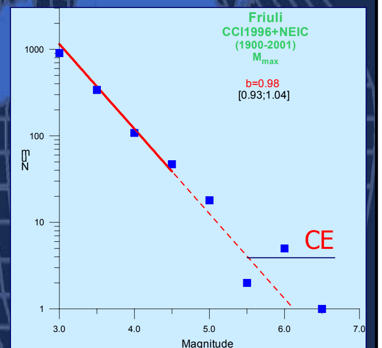
Gutenberg-Richter law



Union of GNDT zones used for the definition of zones of level 1. We show the examples of the Friuli (1976) Irpinia (1980) quakes. The union is given by the GNDT zones where aftershocks have been recorded.

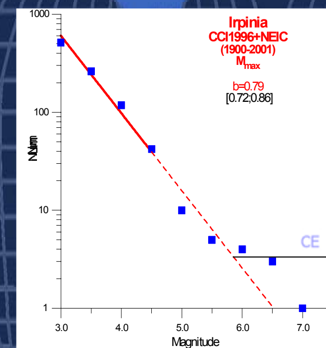
Gutenberg-Richter law

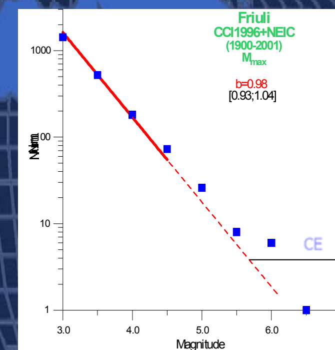




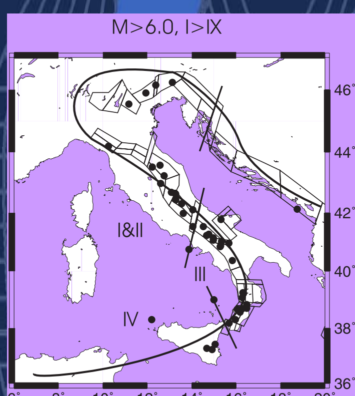
Gutenberg-Richter law

(cumulative distribution)





Gutenberg-Richter law

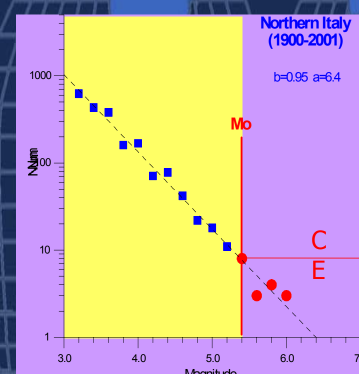


Union of the GNDT zones (Meletti et al., 2000) that define zones of level 2.

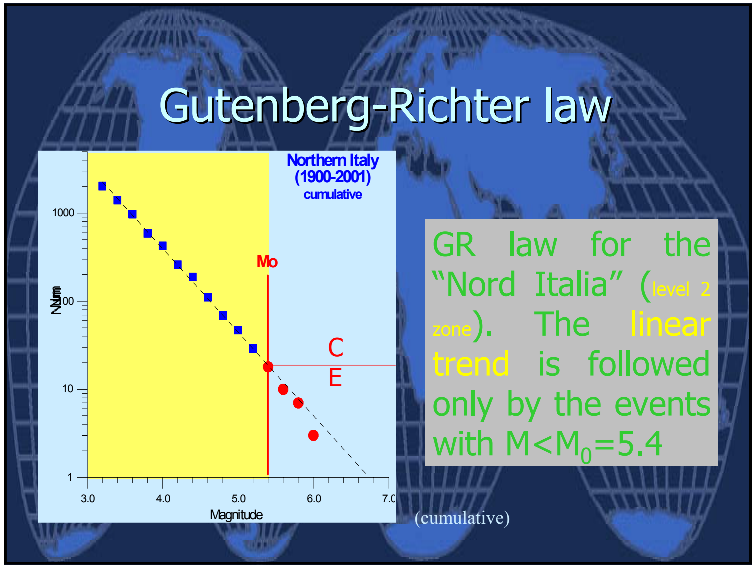
In level 2 zones, with characteristic dimensions of 400-500km, GR law is linear if M<5.4

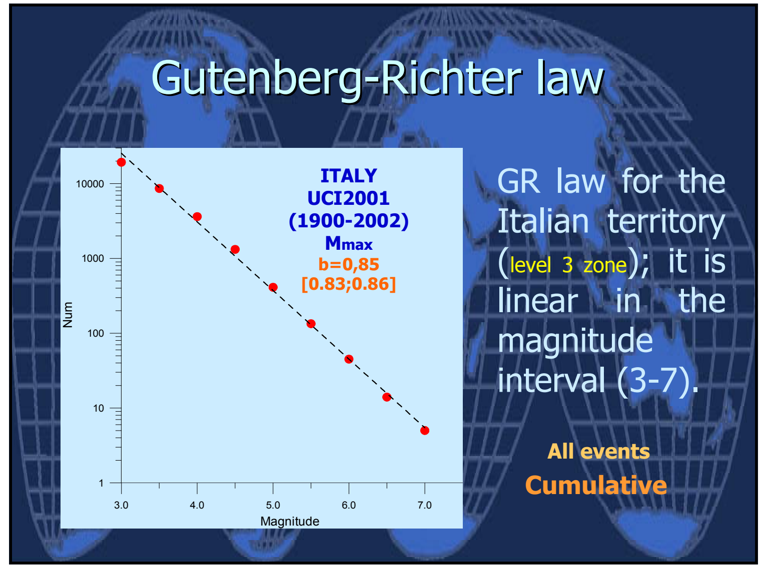
• main events in the period 1000-1980.

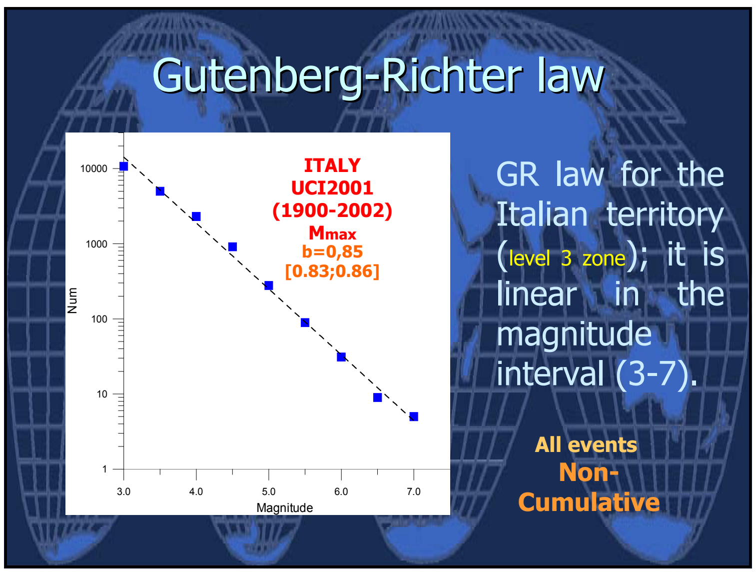
Gutenberg-Richter law

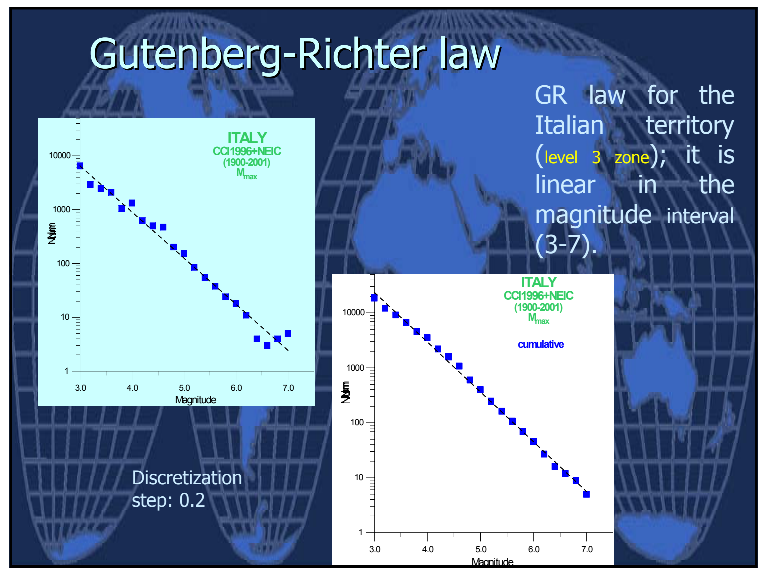


GR law for the "Nord Italia" (level 2 zone). The linear trend is followed only by the events with $M<M_0=5.4$


Gutenberg-Richter law
Northern Italy (1900-2001) cumulative
Mo
C
E
Num
Magnitude
GR law for the "Nord Italia" (level 2 zone). The linear trend is followed only by the events with M<M0=5.4
(cumulative)


Gutenberg-Richter law
ITALY
UCI2001
(1900-2002)
Mmax
b=0,85
[0.83;0.86]
Num
Magnitude
GR law for the Italian territory (level 3 zone); it is linear in the magnitude interval (3-7).
All events
Cumulative

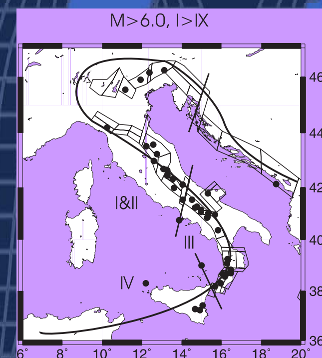

Gutenberg-Richter law
ITALY
UCI2001
(1900-2002)
Mmax
b=0,85
[0.83;0.86]
Num
Magnitude
GR law for the Italian territory (level 3 zone); it is linear in the magnitude interval (3-7).
All events
Non-Cumulative

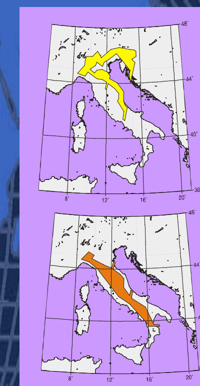

Gutenberg-Richter law
ITALY
CCI1996+NEIC
(1900-2001)
Num
Magnitude
GR law for the Italian territory (level 3 zone); it is linear in the magnitude interval (3-7).
ITALY
CCI1996+NEIC
(1900-2001)
cumulative
Discretization step: 0.2

Gutenberg-Richter law

- The zone of size 400-500 km (level 2) well reproduce the dimensions and shapes of the regions used for the application of the intermediate-term medium-range earthquake prediction algorithm CN.

Gutenberg-Richter law

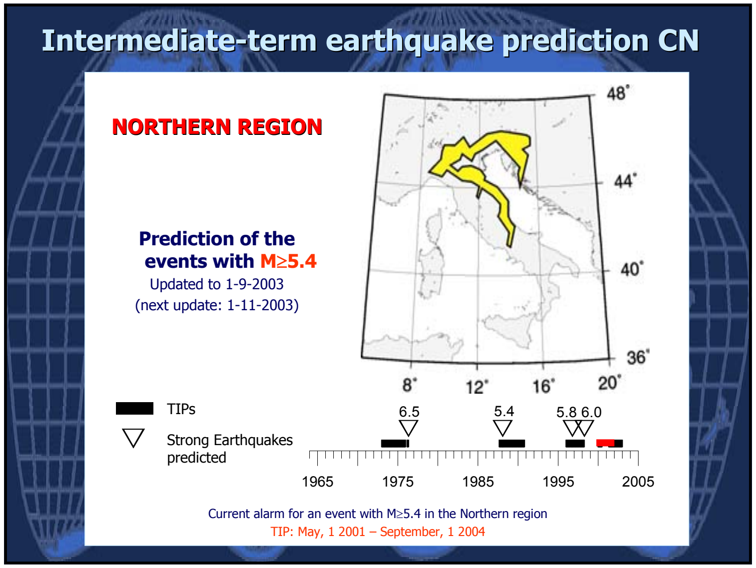


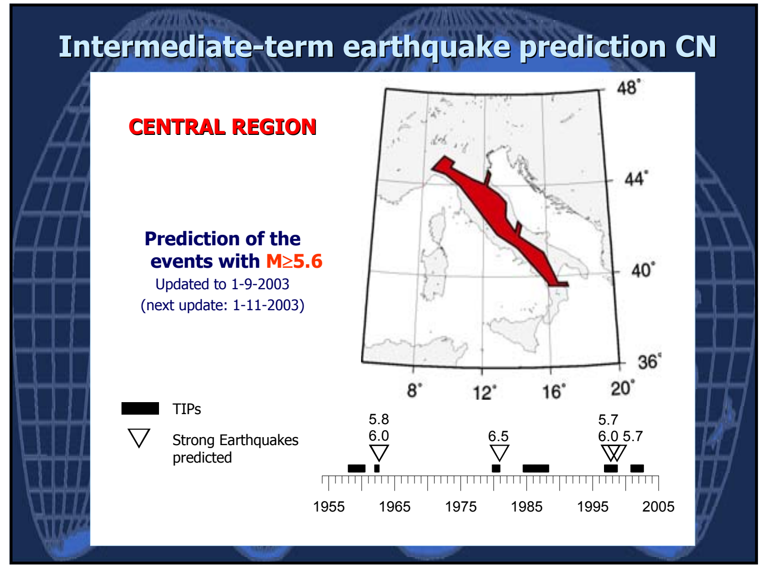


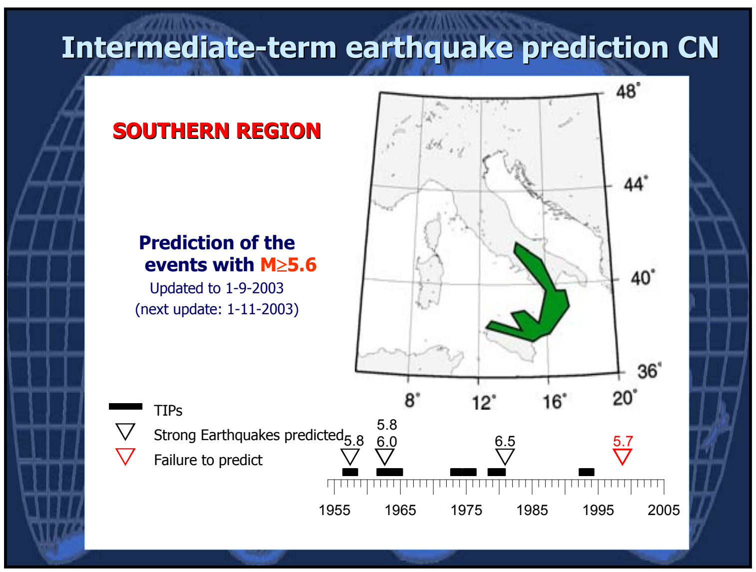
Level 2 zones and CN zones

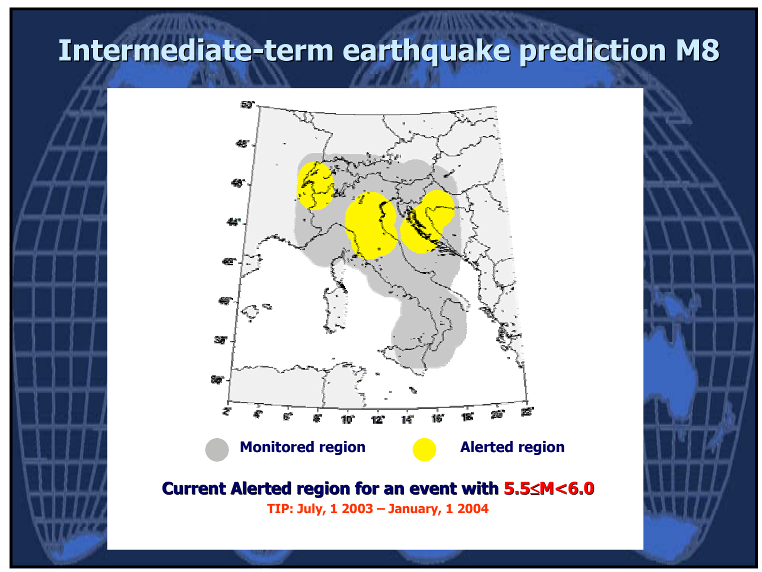
Gutenberg-Richter law

Algorithm CN predicted 76% of the events occurred in the monitored zones in Italy.
It is based on the formal analysis of the anomalies in the flux of the seismic events that follow the GR law, and predicts the strong events ($M>M_0$) that are anomalous (CE) with respect to this law.

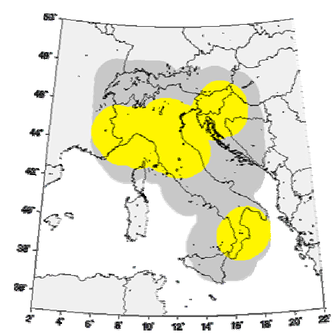

Intermediate-term earthquake prediction CN
NORTHERN REGION
Prediction of the events with M≥5.4
Updated to 1-9-2003
(next update: 1-11-2003)
48˚
44˚
40˚
36˚
8˚
12˚
16˚
20˚
TIPs
Strong Earthquakes predicted
6.5
5.4
5.8 6.0
1965
1975
1985
1995
2005
Current alarm for an event with M≥5.4 in the Northern region
TIP: May, 1 2001 – September, 1 2004


Intermediate-term earthquake prediction CN
CENTRAL REGION
Prediction of the events with M≥5.6
Updated to 1-9-2003
(next update: 1-11-2003)
48˚
44˚
40˚
36˚
8˚
12˚
16˚
20˚
TIPs
Strong Earthquakes predicted
5.8
6.0
6.5
5.7
6.0 5.7
1955
1965
1975
1985
1995
2005


Intermediate-term earthquake prediction CN
SOUTHERN REGION
Prediction of the events with M≥5.6
Updated to 1-9-2003
(next update: 1-11-2003)
48˚
44˚
40˚
36˚
8˚
12˚
16˚
20˚
TIPs
Strong Earthquakes predicted
Failure to predict
5.8
5.8
6.0
6.5
5.7
1955
1965
1975
1985
1995
2005


Intermediate-term earthquake prediction M8
Monitored region
Alerted region
Current Alerted region for an event with 5.5≤M<6.0
TIP: July, 1 2003 – January, 1 2004

Intermediate-term earthquake prediction M8

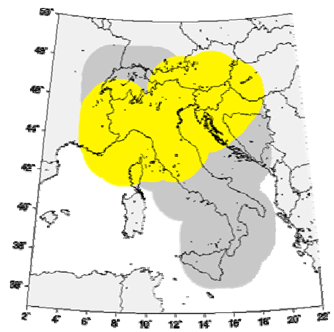


Monitored region   Alerted region

Current Alerted region for an event with 6.0≤M<6.5

TIP: July, 1 2003 – January, 1 2004

Intermediate-term earthquake prediction M8



Monitored region   Alerted region

Current Alerted region for an event with 6.5≤M<7.0

TIP: July, 1 2003 – January, 1 2004

Evaluation of prediction results

The quality of prediction can be defined by using two prediction parameters:

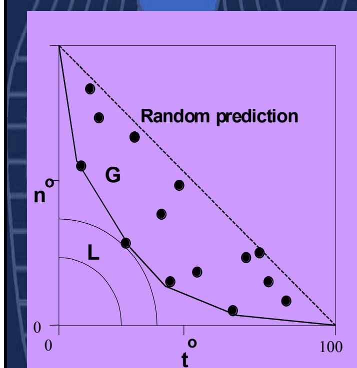
$N^o=n/N$: the rate of failures-to-predict

$T^o=t/T$: the rate of alarm times (*Molchan, 1997*).

N **is the number of strong earthquakes occurred during the time period *T* covered by prediction**

The alarms cover altogether the time *t* and they have missed *n* strong events

Evaluation of prediction results



The performance of the prediction algorithm is characterized by its error curve G, which demonstrates how far from a random guess are the resulting predictions. To make use of prediction and optimise its benefits one needs to specify a cost-benefit function L, i.e. the cost of safety measures imposed by prediction minus the cost of the damage which the measures prevent.

The point where G and L touch each other determines both the minimum loss and the optimal set of parameters in the prediction algorithm to be used for prediction.

Development of decision making procedures for cases of earthquake alarm

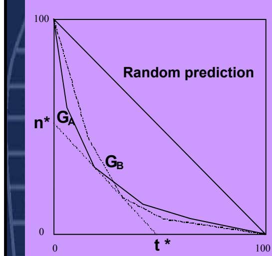
The problem of comparing prediction methods for stationary point processes (like a sequence of strong earthquakes in a region) may be solved using the two prediction parameters:

n^0: the rate of unexpected earthquakes

t^0: the rate of alarm times

(*Molchan, 1997*)

Development of decision making procedures for cases of earthquake alarm



Comparison of algorithms A and B by their error diagrams.

The curves G_A and G_B describe two algorithms: *A* and *B*.
When t^0 is small, G_A is under G_B, algorithm *A* is preferable in application with great values of $\beta/\alpha\lambda$, where β is the cost rate of alert and $\alpha\lambda$ is the loss rate from unexpected earthquakes.
The line (n^*, t^*) is the common line of support for curves G_A and G_B. If $\beta/\alpha\lambda > n^*/t^*$ then the algorithm A is preferable because it yield lesser losses.

IASPEI Preliminary List of Significant Precursors vs. M8 and CN

IASPEI: the observed anomaly should be related to some mechanism leading to earthquakes;

M8 and CN: the equations to describe the dynamics of the lithosphere are still missing thus M8 and CN are algorithms based on empiricism "guided" by the concept of deterministic chaos.

IASPEI: the anomaly should be simultaneously observed at more than one site or instrument;

M8 and CN: give statistically significant results

IASPEI Preliminary List of Significant Precursors vs. M8 and CN

IASPEI: the definition of the anomaly and of the rules for its association with subsequent earthquakes should be precise;

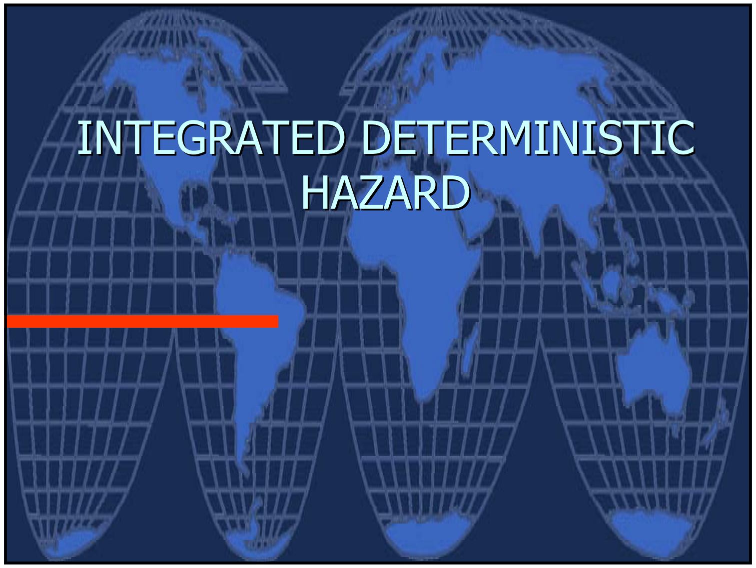
M8 and CN are formalized published algorithms; regular workshops are held at ICTP every second year.

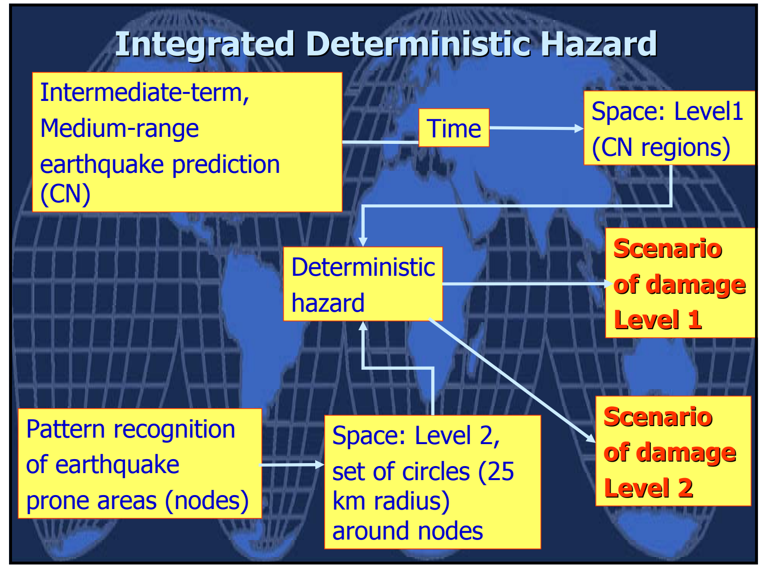
IASPEI: both anomaly and rules should be derived from an independent set of data, than the one for which the precursory anomaly is claimed;

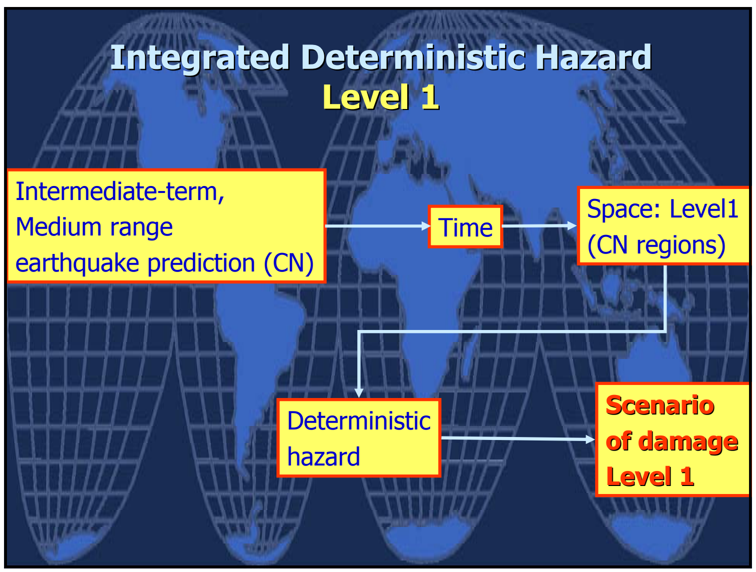
M8 and CN prediction criteria have been defined globally, using information on past seismicity to predict new strong earthquakes.

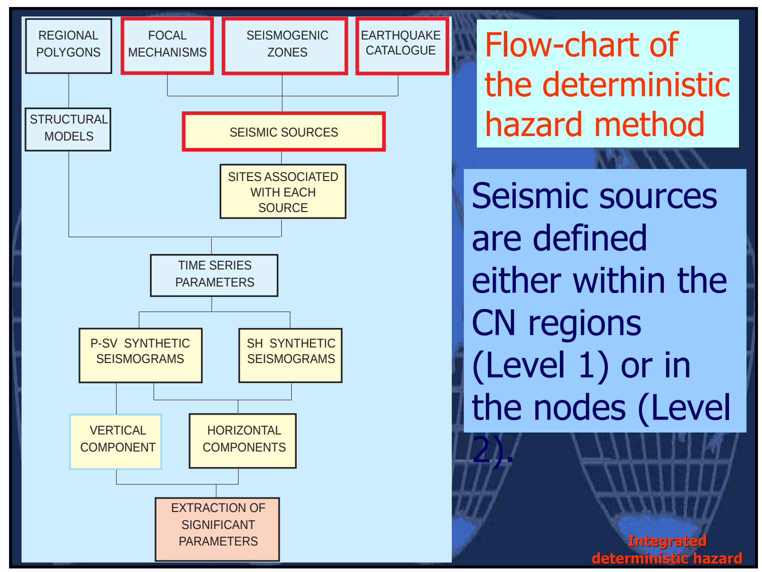
IASPEI Preliminary List of Significant Precursors vs. M8 and CN

None of the precursors from the IASPEI list has been subject to forward prediction testing, while M8 and CN are routinely globally tested.

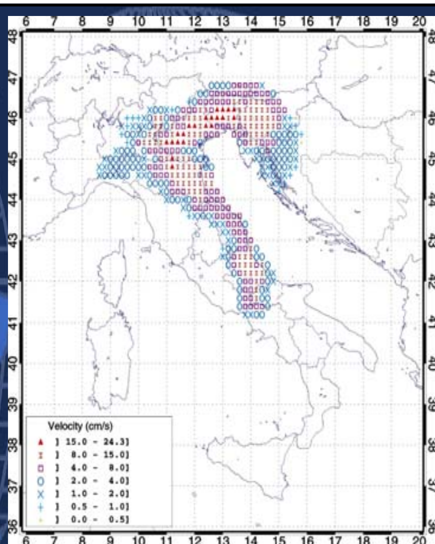

INTEGRATED DETERMINISTIC HAZARD


Integrated Deterministic Hazard
Intermediate-term, Medium-range earthquake prediction (CN)
Time
Space: Level1 (CN regions)
Deterministic hazard
Scenario of damage Level 1
Scenario of damage Level 2
Pattern recognition of earthquake prone areas (nodes)
Space: Level 2, set of circles (25 km radius) around nodes

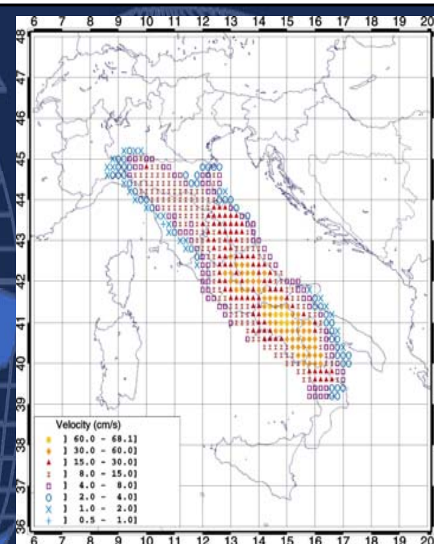

Integrated Deterministic Hazard
Level 1
Intermediate-term, Medium range earthquake prediction (CN)
Time
Space: Level1 (CN regions)
Deterministic hazard
Scenario of damage Level 1


REGIONAL POLYGONS
FOCAL MECHANISMS
SEISMOGENIC ZONES
EARTHQUAKE CATALOGUE
STRUCTURAL MODELS
SEISMIC SOURCES
SITES ASSOCIATED WITH EACH SOURCE
TIME SERIES PARAMETERS
P-SV SYNTHETIC SEISMOGRAMS
SH SYNTHETIC SEISMOGRAMS
VERTICAL COMPONENT
HORIZONTAL COMPONENTS
EXTRACTION OF SIGNIFICANT PARAMETERS
Flow-chart of the deterministic hazard method
Seismic sources are defined either within the CN regions (Level 1) or in the nodes (Level 2).
Integrated deterministic hazard

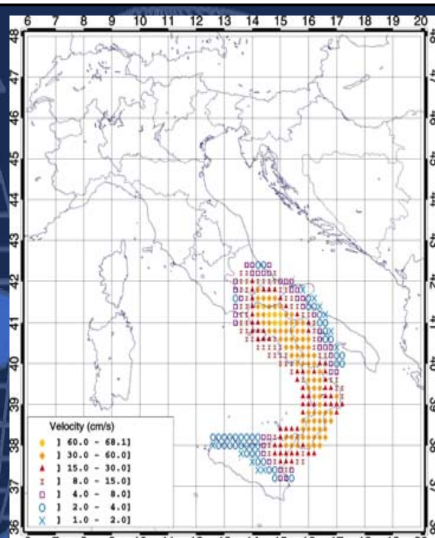
Integrated Deterministic Hazard
-
TIP in Northern region



Integrated Deterministic Hazard
-
TIP in Central region



Integrated Deterministic Hazard
-
TIP in Southern region



Integrated Deterministic Hazard

Impending intensities
for some Italian cities, when a TIP is declared in a CN region

(Regression with ISG observed intensities, Panza et al., 1999)

City	CN region	Imax (observed)	Imax (impending)		
			Displacement	Velocity	DGA
Trieste	north	VII	VIII	VIII	VIII
Bologna	north, centre	VIII	VIII	VIII	IX
Firenze	centre	VIII	VII	VIII	VIII
Roma	centre	VIII	IX	VIII	IX
Napoli	centre,south	VIII	X	IX	IX
Messina	south	X	X	X	X

Integrated Deterministic Hazard Level 2

Pattern recognition of earthquake prone areas (nodes)

Space: Level 2, set of circles (25 km radius) around nodes

Deterministic hazard

Scenario of damage Level 2

Morphostructural Zonation and pattern-recognition of Earthquake Prone Areas

Pattern Recognition of Earthquake Prone areas

- Pattern recognition technique is used to identify sites where strong earthquakes are likely to occur, based on the assumption that strong events nucleate at the nodes, specific structures that are formed around intersections of fault zones.
- Nodes are defined by the Morphostructural Zonation Method, that allows to delineate a hierarchical block structure of the studied region, using tectonic and geological data, with special care to topography.

Pattern Recognition of Earthquake Prone areas

- Unstable tectonic structures are identified evaluating 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

The algorithm for the recognition of Earthquake Prone Areas is used to identify the sites where strong earthquakes are likely to occur, independently from seismicity information. This method is based on the assumption that strong events nucleate at the nodes, specific structures that are formed at the intersections of lineaments. Lineaments are identified by the Morphostructural Zonation (MZS) Method that delineates a hierarchical block structure of the studied region, using tectonic and geological data, with special care to topography. Among the nodes delineated by MSZ, the pattern recognition identifies those that are prone to strong earthquakes on the basis of geologic, geomorphic, and geophysical data excluding seismicity. For recognition purposes the nodes are defined as circles of 25 km radius, centred at the intersections of the lineaments.

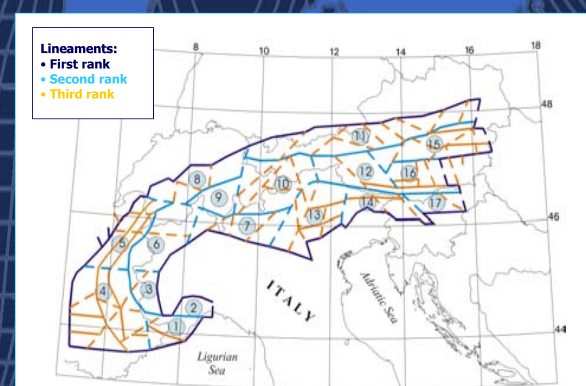
The results of the recognition, obtained for a large number of seismic regions, have been proved by the subsequent occurrence of strong earthquakes at several of the recognised earthquake prone areas. The predictions made worldwide in the last 3 decades have been followed by many events (84% of the total) that occurred in some of the nodes previously recognized to be the potential sites for the occurrence of strong events. In peninsular Italy and Sicily, this study has allowed us to identify the sites where stronger events, with magnitude larger or equal to 6.0 or 6.5, may occur . The results of the classification of the nodes for both magnitude thresholds are in good agreement with the recorded seismicity; in fact almost all (more than 90%) of the past strong earthquakes occurred at the recognised nodes. A similar analysis has been recently performed for the Alps and the Dinarides leading to the identification of the nodes prone to earthquakes with M≥6.0 or M≥6.5.

Lineaments and numbering of Nodes in peninsular Italy and Sicily

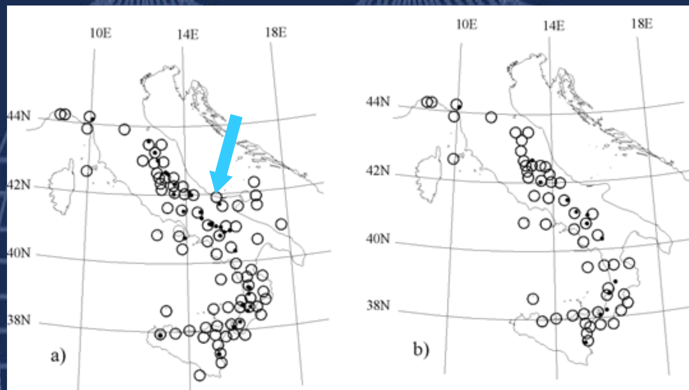
Lineaments:
• First rank
• Second rank
• Third rank

Gorshkov et al. (2002)

Morphostructural zonation of the Alps and numbering of Blocks

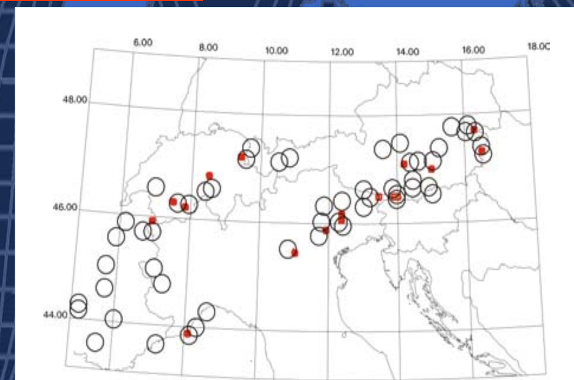


Gorshkov et al. (2003)



Recognition of earthquake prone nodes in peninsular Italy and Sicily. Nodes (circles) prone to earthquakes with M≥6.0.(a) and with M≥6.5 (b). Dots denote the epicentres of the recorded events with magnitude larger than 6.0 and 6.5, respectively.

Observed epicentres and Nodes Prone to Earthquakes with M≥6.0 in the Alps

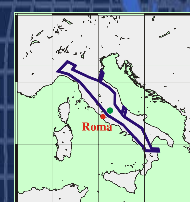


Gorshkov et al. (2003)

Lineaments and numbering of Nodes in the Alps and Dinarides

Gorshkov et al. (2003)

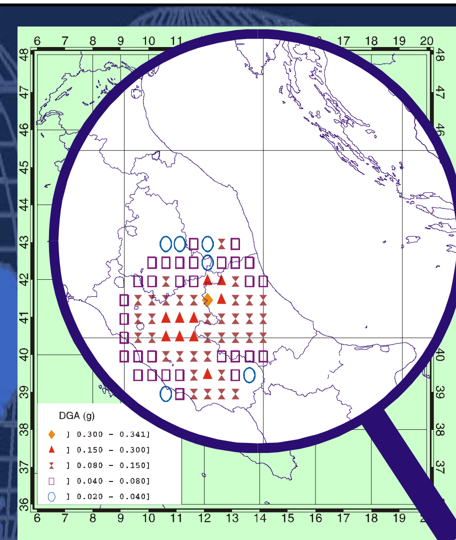
Integrated Deterministic Hazard



Roma

Imax(expected): IX

Imax(observed):VIII



Integrated Deterministic Hazard

Impending intensities for events with M≥6.5

(Regression with ISG observed intensities, Panza et al., 1999)

City	CN region	N□of Circles	Imax (observed)	Imax (impending [3])		
				Displacement	Velocity	DGA
Bologna	centre	1	VIII	VIII	VIII	VIII
Firenze	centre	2	VIII	VII	VIII	VIII
Roma	centre	8	VIII	IX	VIII	VIII
Napoli	centre south	5	VIII	X	IX	IX
Messina	south	9	X	X	X	X