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14 - 18 May 2007

Time dependent neo-deterministic seismic hazard assessment and earth-observation: the ASI-SISMA project and its possible contribution to IDRiM implementation strategies

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Time dependent neo-deterministic seismic hazard assessment and earth-observation: the ASI-SISMA project and its possible contribution to IDRiM implementation strategies

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МИТПАН
ИЕРТ

The Abdus Salam International Centre for Theoretical Physics

UNIVERSITÀ DEGLI STUDI DI TRIESTE

DST

Outline

- Some general problems in probabilistic seismic hazard assessment
  - Detail of probabilistic maps
  - GR law and the recurrence of earthquakes
  - Attenuation relations and PSHA
- Time dependent neo-deterministic seismic hazard assessment
  - Real-time monitoring of the seismic flow
  - Pattern-recognition of earthquake prone areas
  - Multiscale neo-deterministic seismic hazard scenarios
- The ASI-SISMA project: using data from earth-observations
- IDRiM Integrated Disaster Risk Management

Seismic hazard assessment: some limits of the probabilistic approach

ELSEVIER

Engineering Geology 66 (2002) 315–317

ENGINEERING GEOLOGY

www.elsevier.com/locate/enggeo

Opinion paper

PSHA: is it science?

Heriberta Castaños [a], Cinna Lomnitz [b,*]

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Abstract

Probabilistic seismic hazard analysis (PSHA) is beginning to be seen as unreliable. The problem with PSHA is that its data are inadequate and its logic is defective. Much more reliable, and more scientific, are deterministic procedures, especially when coupled with engineering judgment.

Keywords: Probabilistic seismic hazard analysis; Deterministic seismic hazard analysis; Earthquakes

Probabilistic vs. Deterministic

- The two methodologies, **probabilistic** and **deterministic,** have some common elements, such as the characterization of seismicity in the area, the geological and geotechnical conditions and the size of the expected earthquakes.
- Lessons from recent earthquakes (e.g. Kobe, Japan; Bam, Iran; Boumerdes, Algeria) indicate that the available observations may be not sufficiently representative of the seismic hazard in a given region.
- Case studies of seismic hazard assessment techniques indicate the limits of the currently used methodologies, deeply rooted in engineering practice, based prevalently on a probabilistic approach.
- In view of the limited seismological data, it seems more appropriate to resort to a scenario-based deterministic approach.

? GSHAP ?

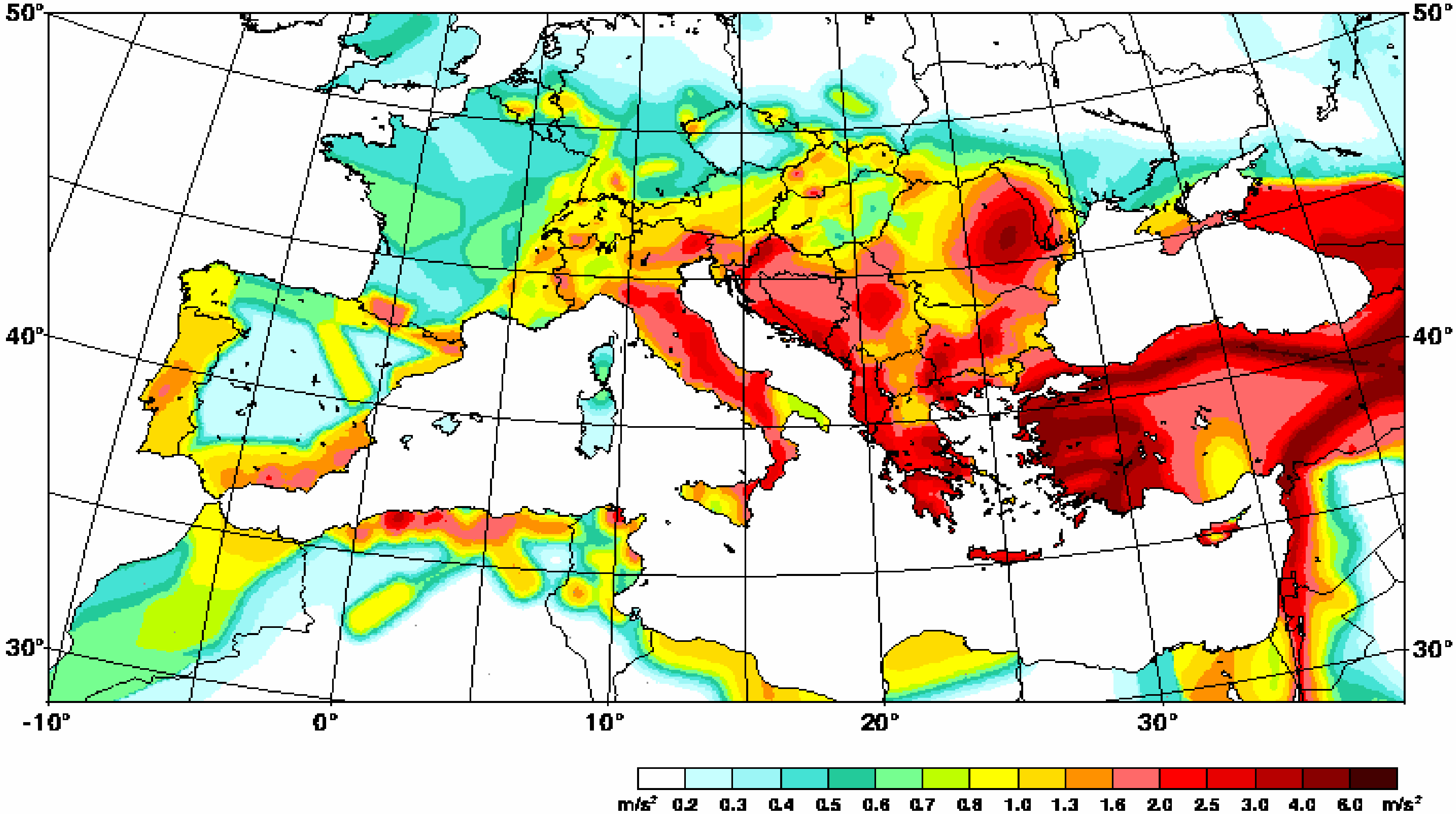
The probabilistic analysis supplies indications that can be useful but are not sufficiently reliable to characterize seismic hazard. Recent examples Kobe (17.1.1995), Bhuj (26.1.2001), Boumerdes (21.5.2003) and Bam (26.12.2003) events.

	PGA(g) Expected with a probability of exceedence of 10% in 50 years (return period 475 years)	Observed
Kobe	0.40-0.48	0.7-0.8
Gujarat	0.16-0.24	0.5-0.6
Boumerdes	0.08-0.16	0.3-0.4
Bam	0.16-0.24	0.7-0.8

? GSHAP ?

- The *detail* given by the probabilistic maps proposed by GSHAP, when the input information mainly consists of macroseismic intensities, is, in general, an *artefact* of the processing.
- This limitation to the practical use of GSHAP maps is particularly severe when dealing with large urban settlements or special objects.

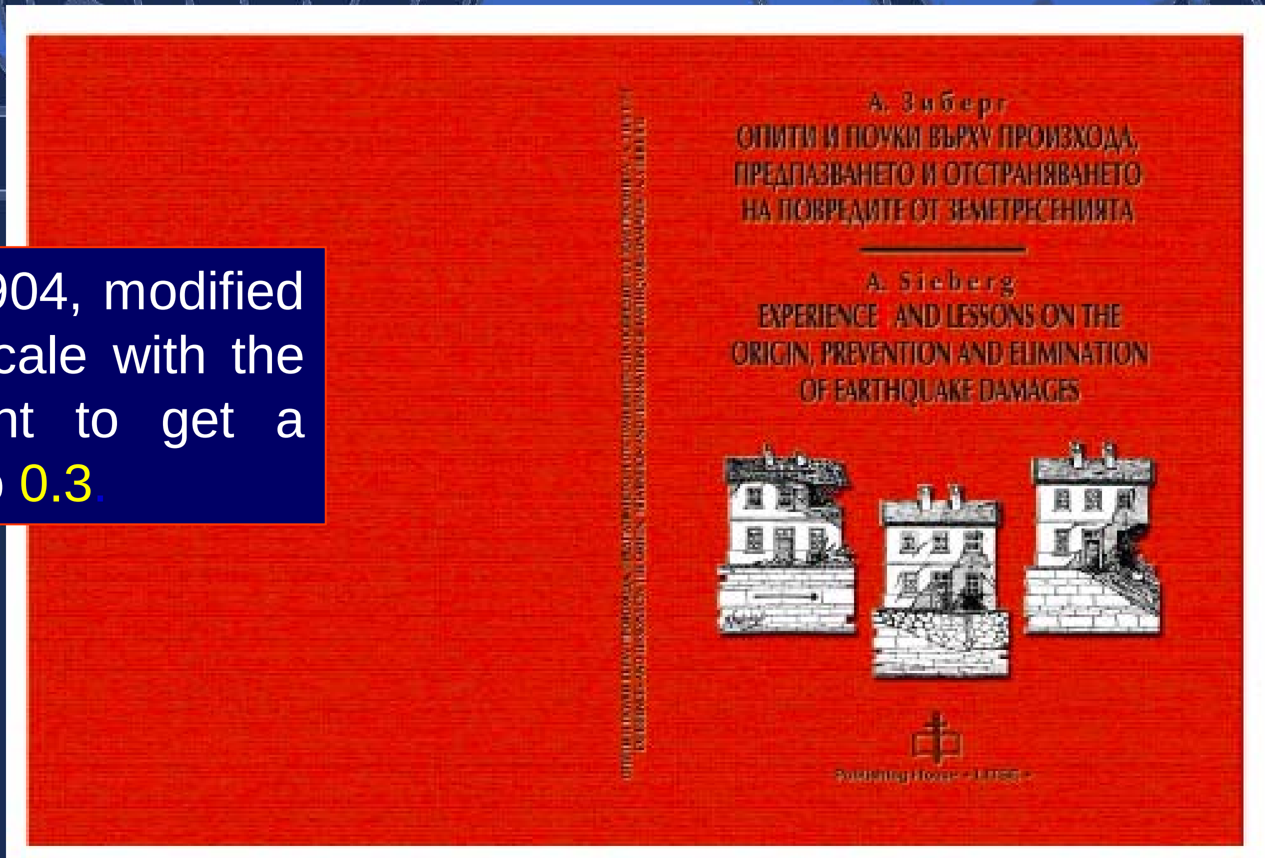
The GSHAP probabilistic map at 475 years



Horizontal Peak Ground Acceleration seismic hazard map representing stiff site conditions for an exceedance or occurrence rate of 10% within 50 years for the Mediterranean region.

The log-linear regression between maximum observed macroseismic intensity, I (MCS), and computed peak values of ground motion (A), considering historical events, has a slope close to 0.3 (see Panza et al., 1999; Shteinberg et al., 1993 and references therein):

$$\text{Log } A = a + bI$$



Cancani, in 1904, modified the Mercalli scale with the declared intent to get a slope equal to 0.3.

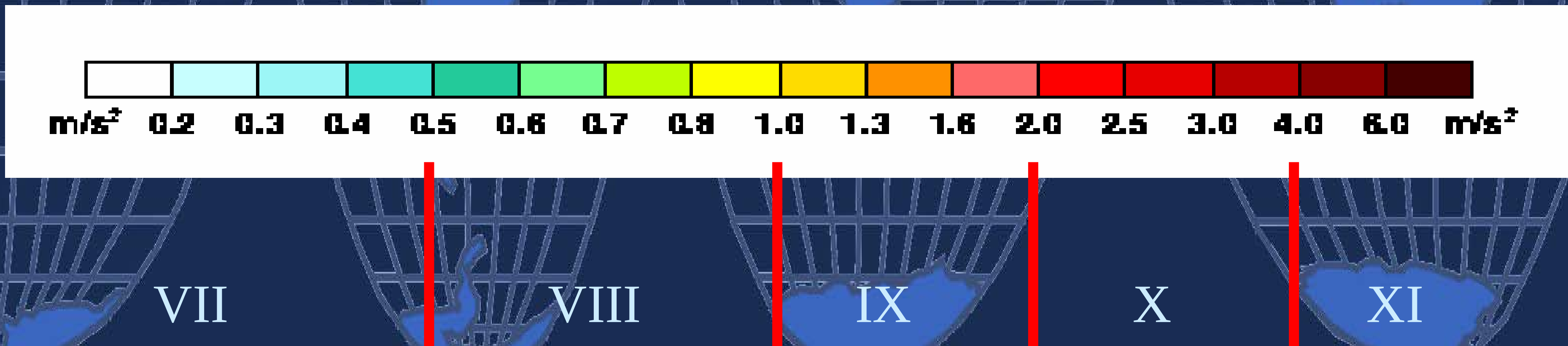
Hence one degree of intensity corresponds to a factor two in the values of ground motion:

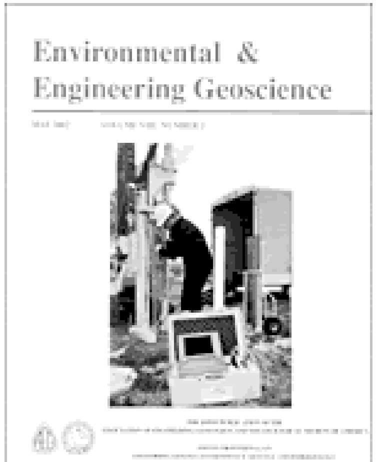
DGA(I-1)/DGA(I)=2

PGV(I-1)/PGV(I)=2

PGD(I-1)/PGD(I)=2

Comparison between GSHAP scale used in the Mediterranean, and MCS Intensity scale





Environmental & Engineering Geoscience
Quarterly

Co-published by GSA and the Association of Engineering Geologists, this respected journal presents new theory applications and case histories illustrating the dynamics of the fast-growing environmental and applied disciplines. About 700 pages annually.

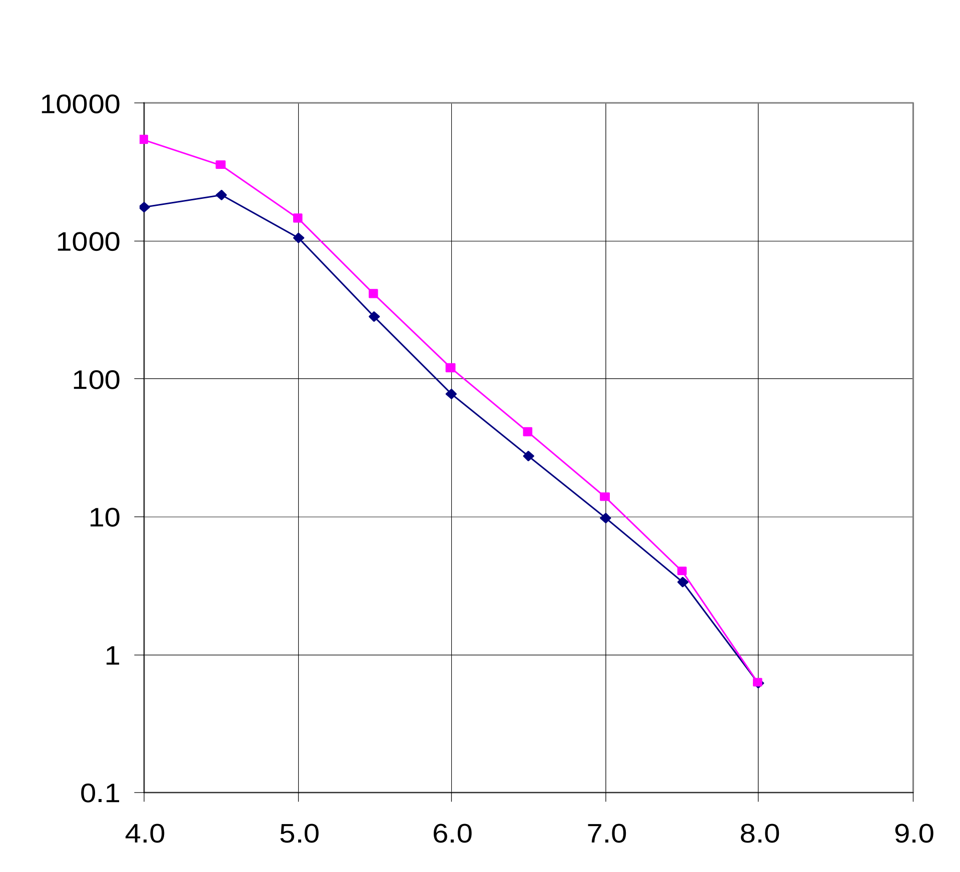
Nov 1998, 4, 425-443

The hazard in using probabilistic seismic hazard analysis for engineering

Ellis L. Krinitzsky
Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS, United States

……..The problem with seismic probability is that it relies on the Gutenberg-Richter b-line, which has severe shortcomings……..

The Gutenberg-Richter law



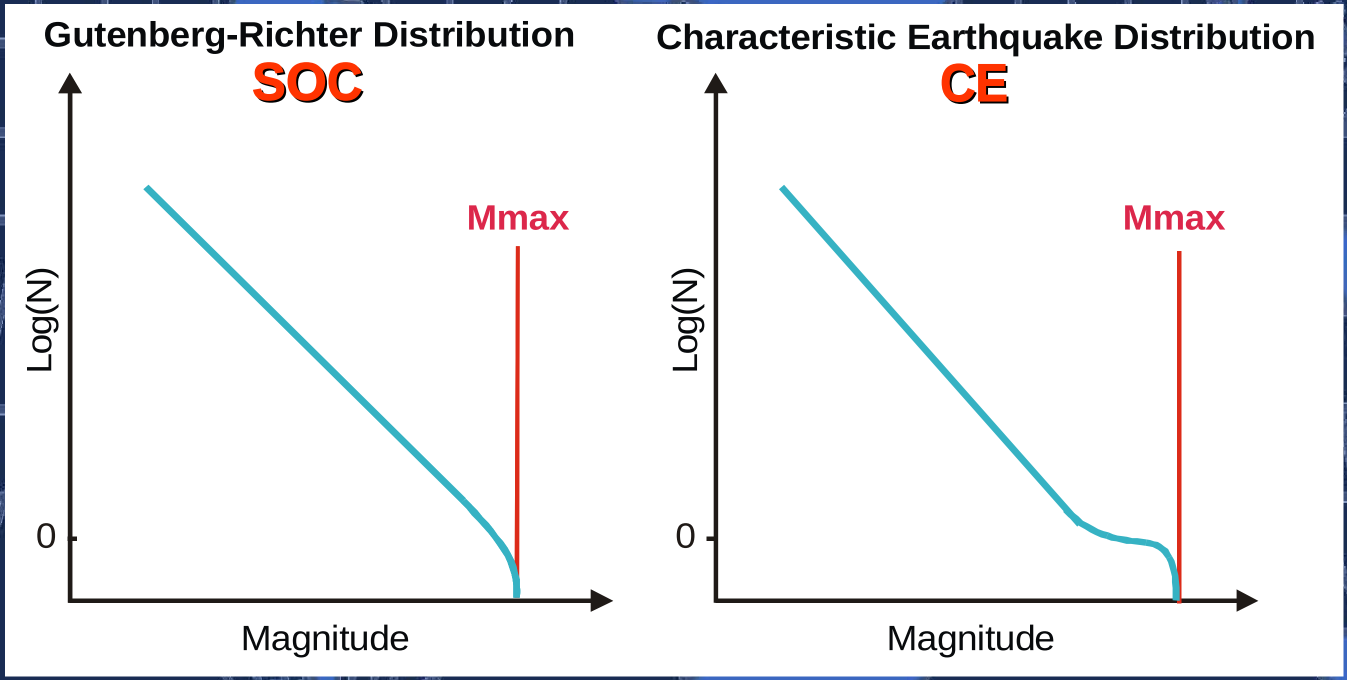
Averaged over a large territory and time the number of earthquakes equal or above certain magnitude, N(M) scales as:

$$\log_{10} N(M) = a - bM$$

This general law of similarity establishes the scaling of earthquake sizes in a given space time volume but gives no explanation to the question how the number, N, changes when you zoom the analysis to a smaller size part of this volume.

Multiscale seismicity model

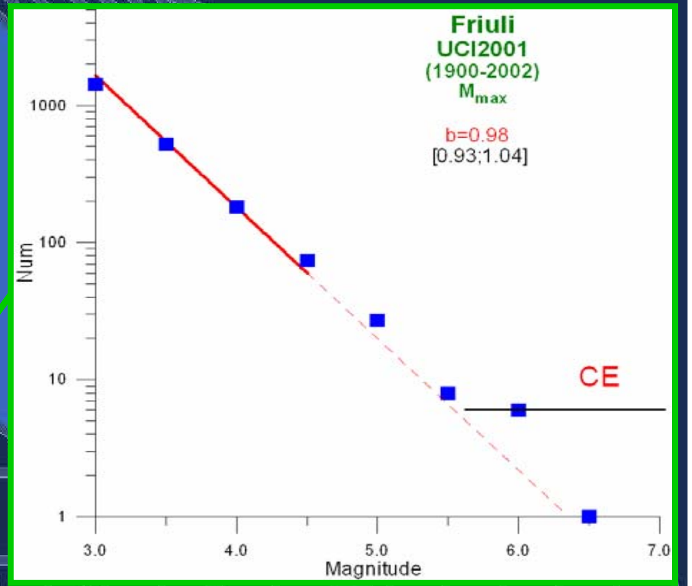
- The analysis of global seismicity shows that a single Gutenberg-Richter (GR) law is not universally valid and that a **Multiscale seismicity model** (*Molchan, Kronrod & Panza, BSSA, 1997*) can reconcile two apparently conflicting paradigms: the **Characteristic Earthquake (CE)** model and the **Self-Organized Criticality (SOC)** concept.



Multiscale seismicity model

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

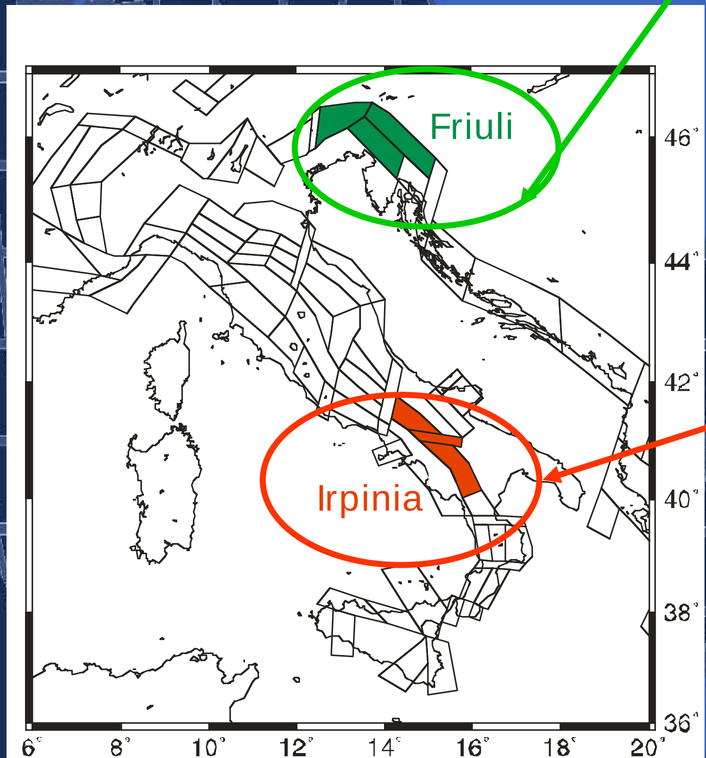
- This condition, fully satisfied in the study of global seismicity made by Gutenberg and Richter, has been violated in many subsequent investigations.

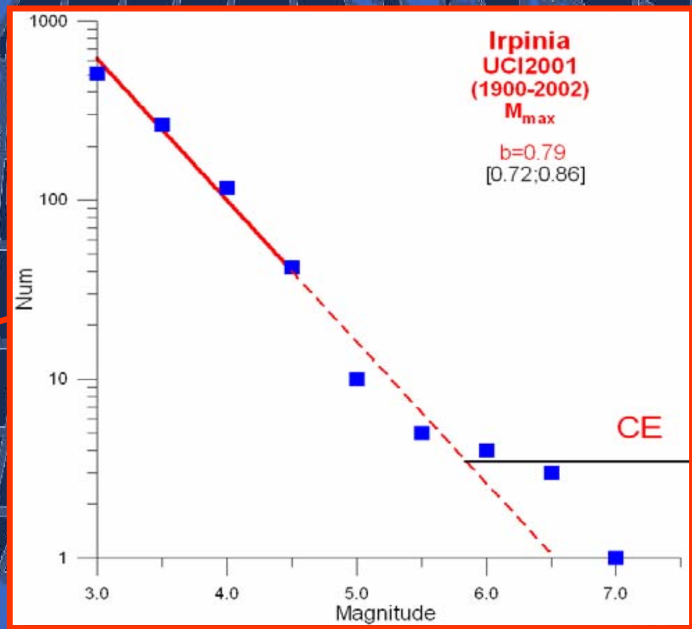


Union of the seismogenic zones, as defined by GNDT (Meletti et al., 2000) where aftershocks have been recorded.

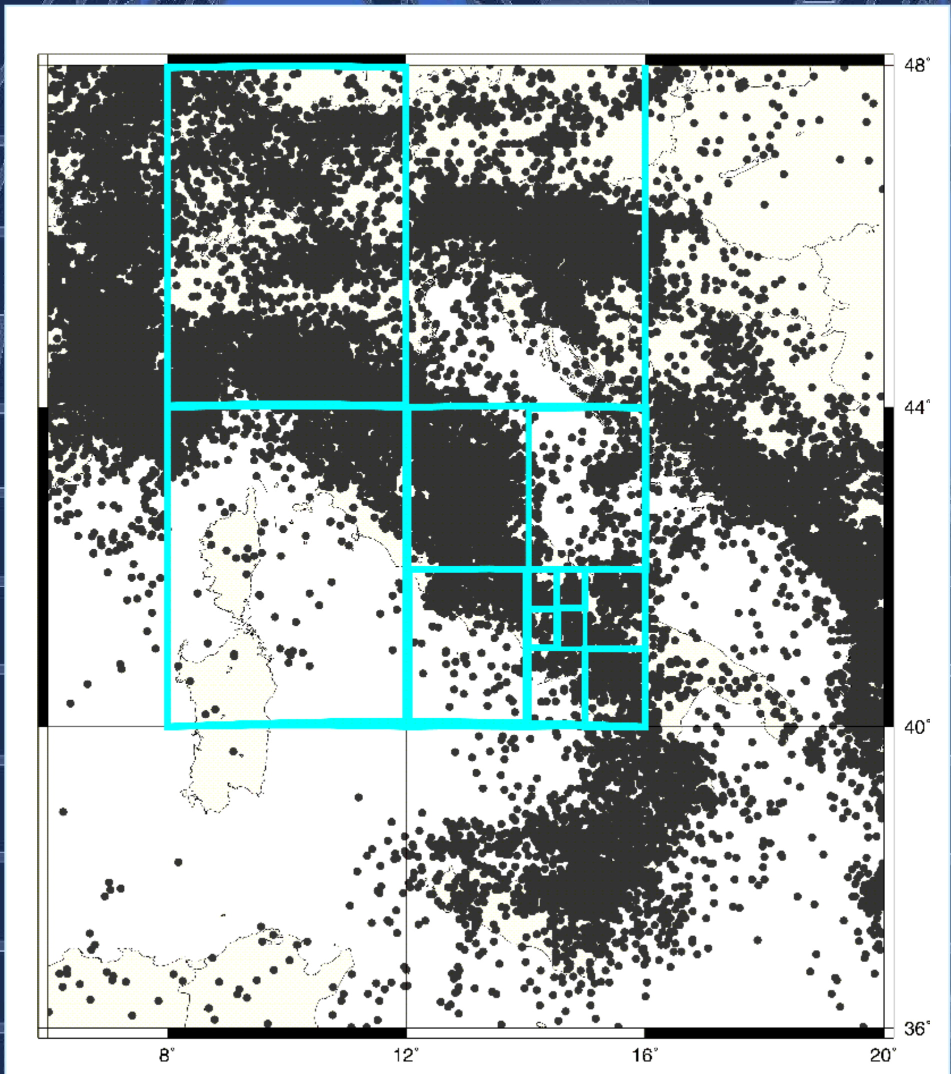
(Zones with characteristic dimensions of 200-300km)

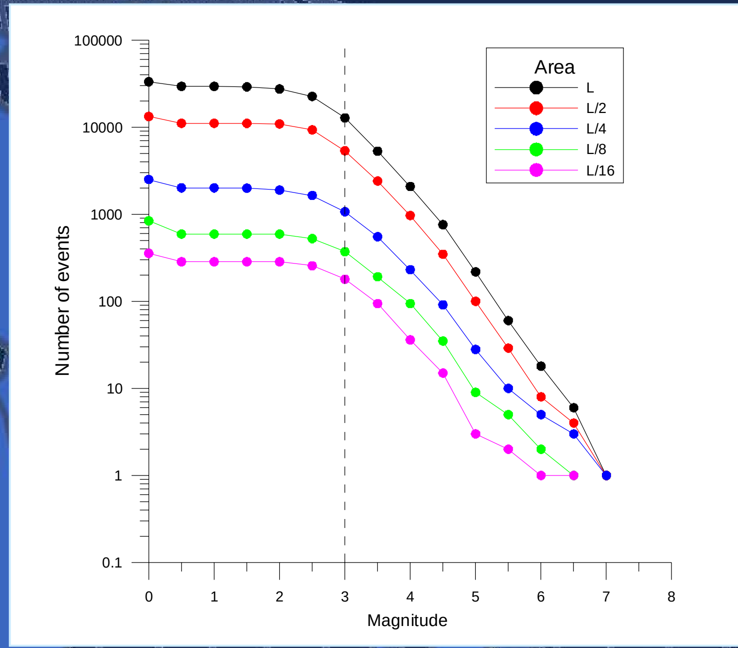
Examples of the Friuli (1976) and Irpinia (1980) quakes.

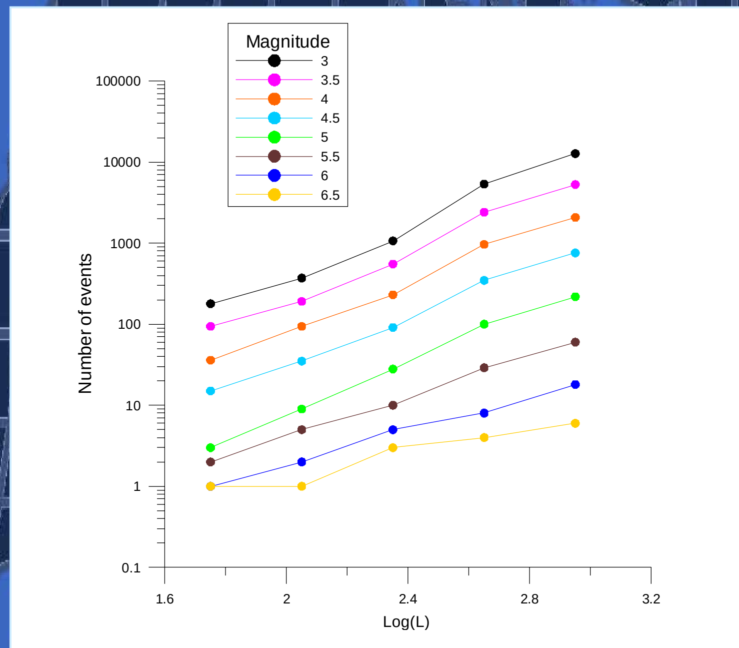




Multiscale seismicity model

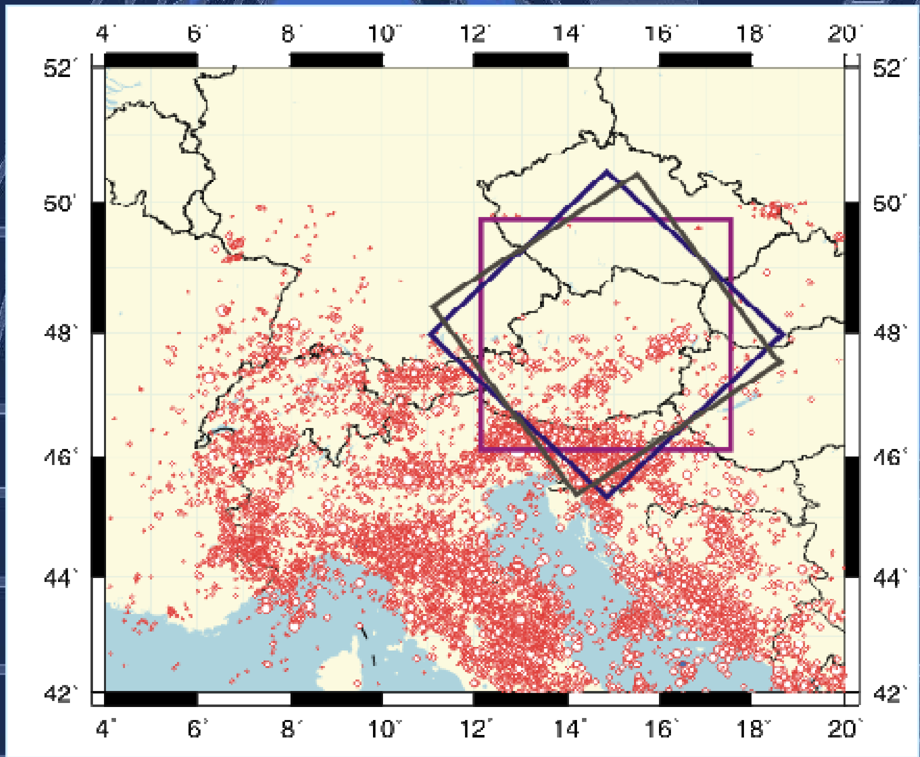






UCI2001 catalogue
1900-2002

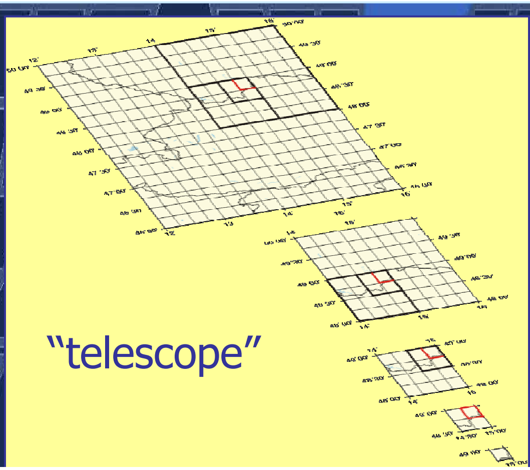
Unified Scaling Law for Earthquakes (USLE)



The counts of earthquakes is performed in a set of cascading squares, **"telescope"** ⇒ permits to account for the natural scaling of the spatial distribution of epicenters and provides evidence for rewriting the Gutenberg-Richter recurrence law in the generalised form:

$$\log_{10}N = A + B\cdot(5 - M) + C\cdot\log_{10}L$$

where N = N(M, L) is the expected annual number of earthquakes with magnitude M in an area of linear dimension L.

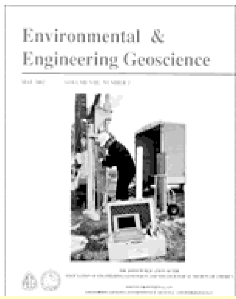


The scheme for box-counting

The algorithm allows for multiple rotation of settings on a randomly selected angle.

Kossobokov, V.G., and S.A. Mazhkenov, 1994. On similarity in the spatial distribution of seismicity. Computational Seismology and Geodynamics, 1: 6-15 AGU, Washington, D.C.

USLE: implications for seismic hazard assessment



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Nov 1998, 4, 425-443

………The problem with seismic probability is that it relies on the Gutenberg-Richter b-line, which has severe shortcomings………

- The USLE, which accounts for the spatial scaling of the distribution of epicenters, may have relevant implications for assessing seismic hazard at a given location (e.g. in a mega city).

⇒ Neglecting the $C \cdot \log_{10} L$ term implies an underestimation of the recurrence of earthquakes by a factor $(L_0 / L)^{2-C}$.

Example: The USLE estimates for Los Angeles (SCSN data, 1984-2001) are:

$A = -1.28; \quad B = 0.95; \quad C = 1.21 \ (\sigma_{total} = 0.035)$

imply a traditional assessment of recurrence of a large earthquake in Los Angeles, i.e., an area with L about 40 km, from data on the entire southern California, i.e., an area with L_0 about 400 km, being underestimated by a factor $10^2 / 10^{1.21} = 10^{0.79} > 6$

Attenuation relations and PSHA

- The attenuation relation in the form*:*

$$\ln\,(S_a(m,r)) = g(m,r) + \varepsilon\sigma$$

describes the dependency of the spectral acceleration on the random variates, magnitude, distance and measurement error (Klügel, 2007).

- PSHA: The laws of multivariate theory of probability are applied to calculate the conditional probability of exceedance of a certain hazard level z for a given set of parameters m and r (assuming independence between m and r).

- PSHA approximation: $g(m,r)$ is constant and all the randomness of the problem is concentrated in the error term ε (univariate approximation). Hence:

$$\ln\,(S_a(m,r)) = \boxed{E(g(m,r))} + \varepsilon\sigma$$

"quasi-deterministic" term of ground motion

(Klugel, 2007)

Attenuation relations and PSHA

- The substitution of a random parameter by its expected value introduces a systematic error. This is demonstrated simply replacing the distribution $g(m,r)$ by its development into a series around its expected value $E(g(m,r))$:

$$g(m,r) = E(g(m,r)) + \Delta(m,r)$$

where $\Delta(m,r)$ is a non-trivial random variable (i.e. not equal to zero). This yields:

$$\ln(S_a(m,r)) = E(g(m,r)) + \Delta + \varepsilon\sigma$$

$\Rightarrow$ Replacing this expression in the PSHA approximation we get $\Delta = 0$, in contradiction with the definition of $\Delta(m,r)$.

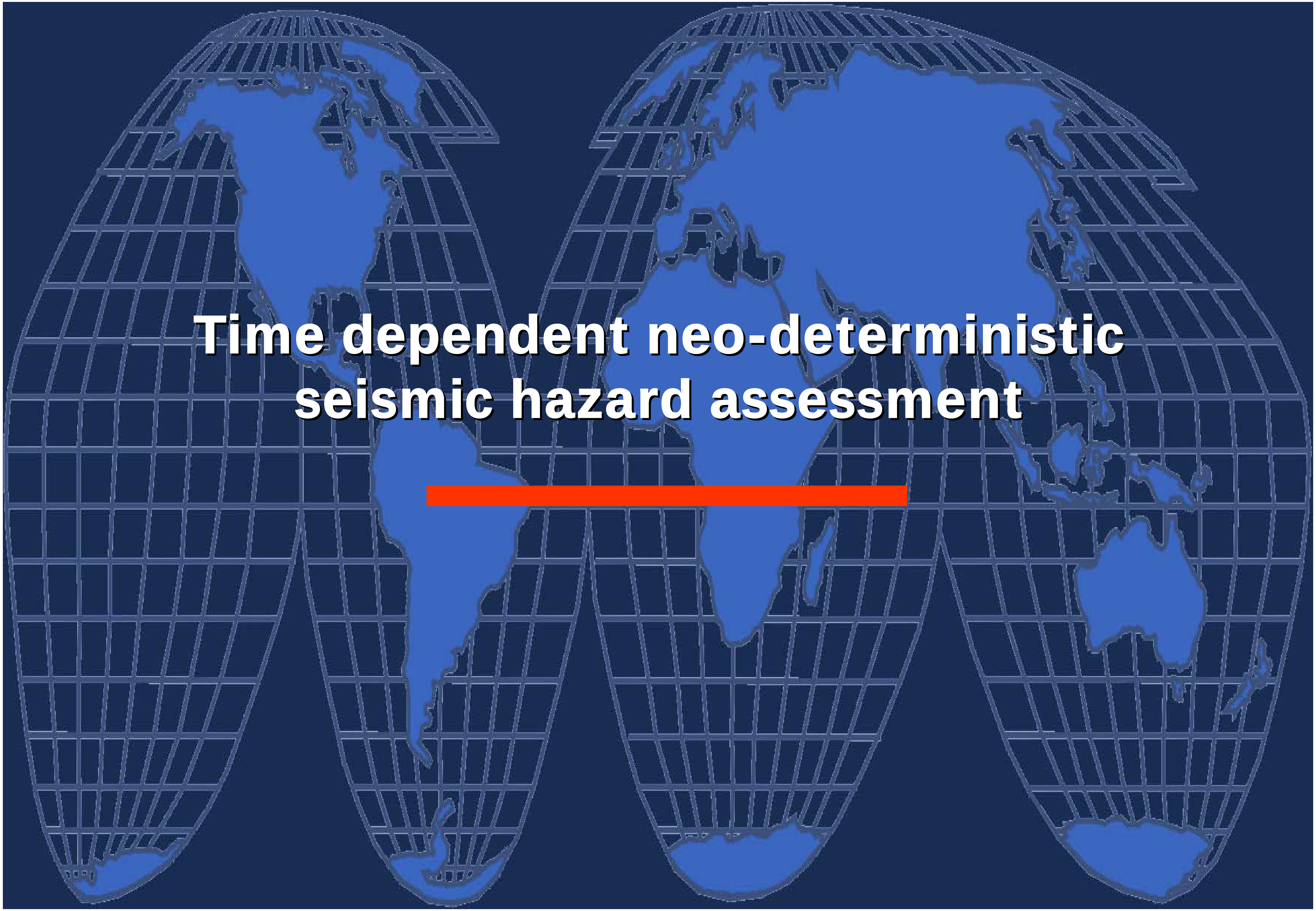
(Klugel, 2007)

Attenuation relations and PSHA

- This systematic error is not easy to quantify, since it depends on the value of ground motion acceleration. Qualitatively:
  - For slight perturbations of ground motion accelerations around the regression mean of the attenuation equation (i.e. for high probabilities of exceedance of a PSHA model) $\Rightarrow$ the error is small;
  - For low probabilities of exceedance, where it is not possible to approximate $g(m,r)$ with its expected value $\Rightarrow$ the error is high.
- The use of intensities, instead of accelerations, in the probabilistic model reduces the error effect , since I is a composite parameter that combines information on spectral acceleration and magnitude.

(Klugel, 2007)

Time dependent neo-deterministic seismic hazard assessment



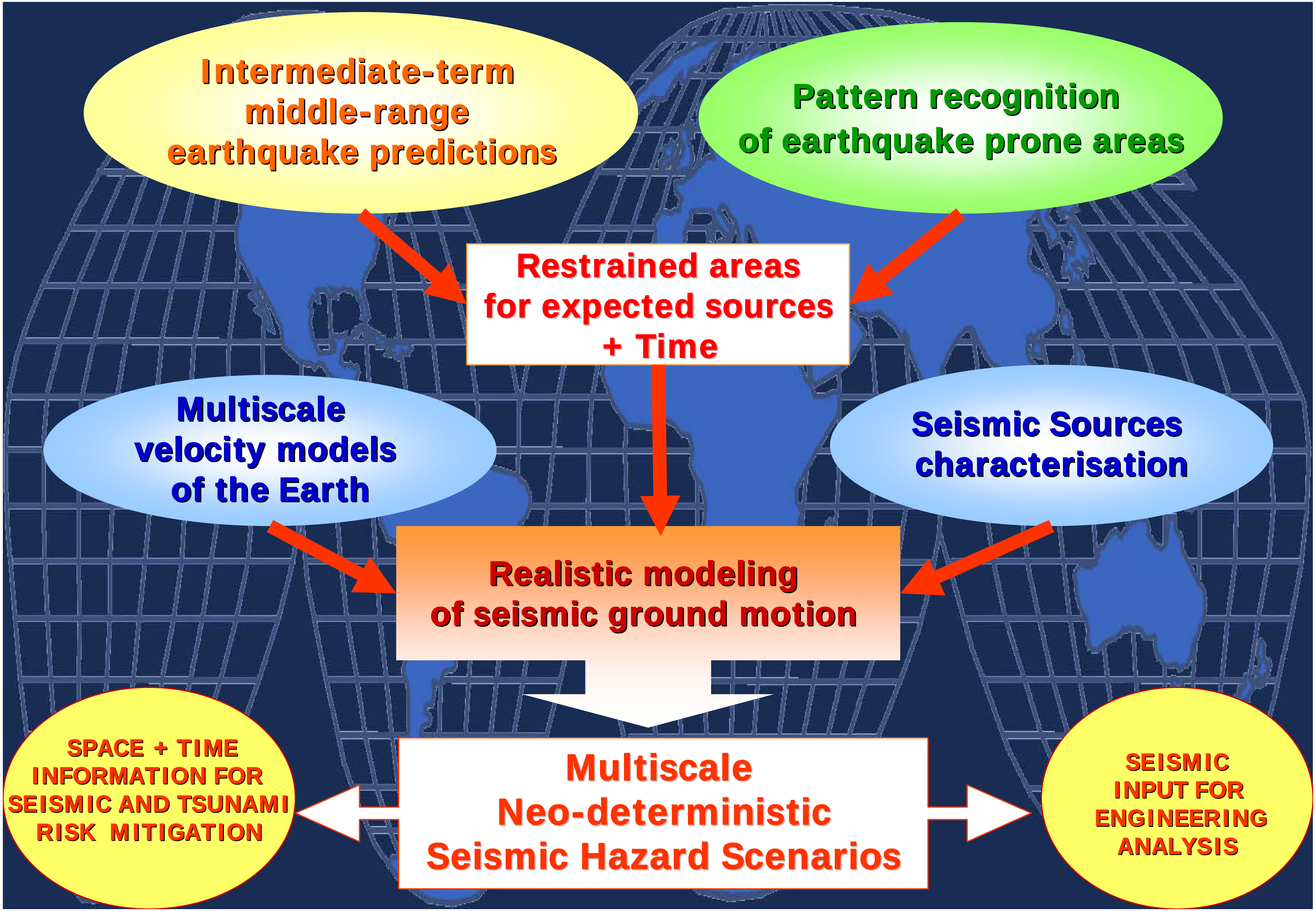
Neo-deterministic seismic hazard assessment

- The procedure for the neo-deterministic seismic hazard assessment is based on the possibility to compute realistic synthetic seismograms by the modal summation technique;

- The expected ground motion can be modeled at any desired point, starting from the available information about seismic sources and regional structural models.

Neo-deterministic seismic hazard assessment

- The neo-deterministic approach defines the hazard from the envelope of the values of ground motion parameters (like acceleration, velocity or displacement) determined considering scenario earthquakes consistent with seismic history and seismotectonics;
- It allows incorporating the space-time information provided by intermediate-term earthquake predictions and pattern recognition of earthquake prone areas.


Intermediate-term
middle-range
earthquake predictions
Pattern recognition
of earthquake prone areas
Restrained areas
for expected sources
+ Time
Multiscale
velocity models
of the Earth
Seismic Sources
characterisation
Realistic modeling
of seismic ground motion
SPACE + TIME
INFORMATION FOR
SEISMIC AND TSUNAMI
RISK MITIGATION
Multiscale
Neo-deterministic
Seismic Hazard Scenarios
SEISMIC
INPUT FOR
ENGINEERING
ANALYSIS

Real-time monitoring of the seismic flow: CN and M8S algorithms in Italy

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 make use of detectable inverse cascade of seismic process, at different space and time ranges, to reduce consecutively space and time limits where a disastrous earthquake has to be expected.

CN algorithm in Italy

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

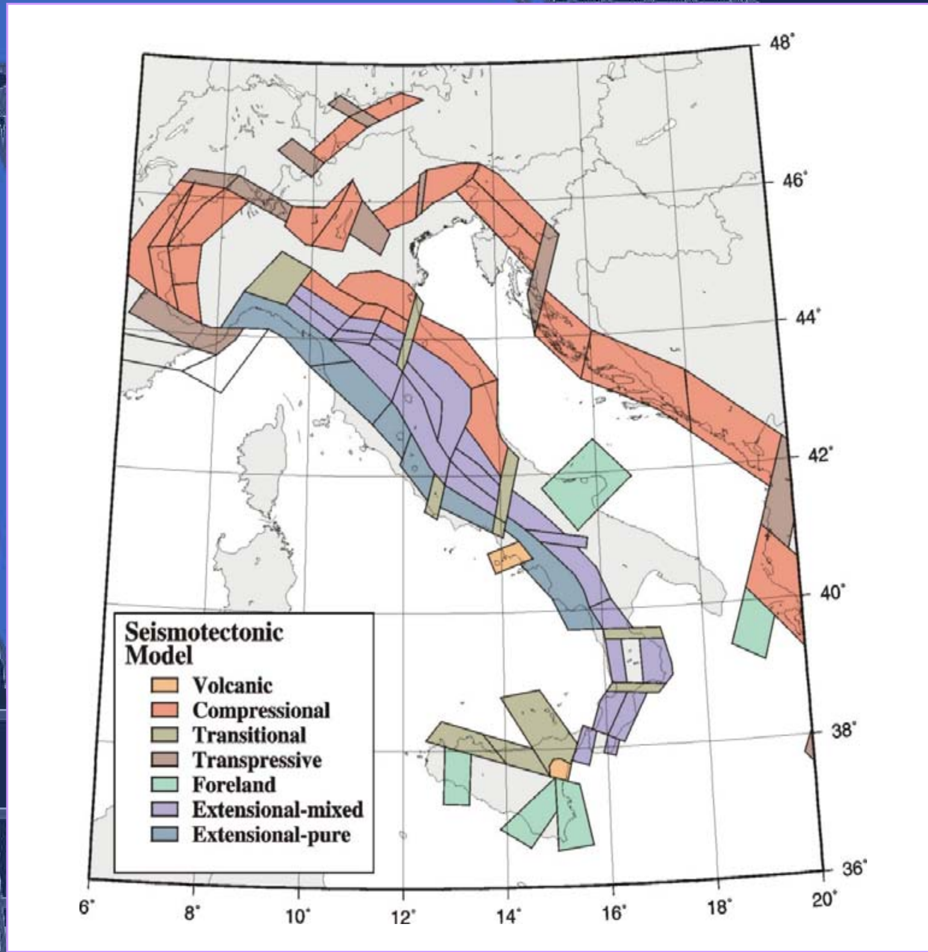
A single region includes:

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)

Rules for CN application and selection of target events

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

Magnitude of completeness:

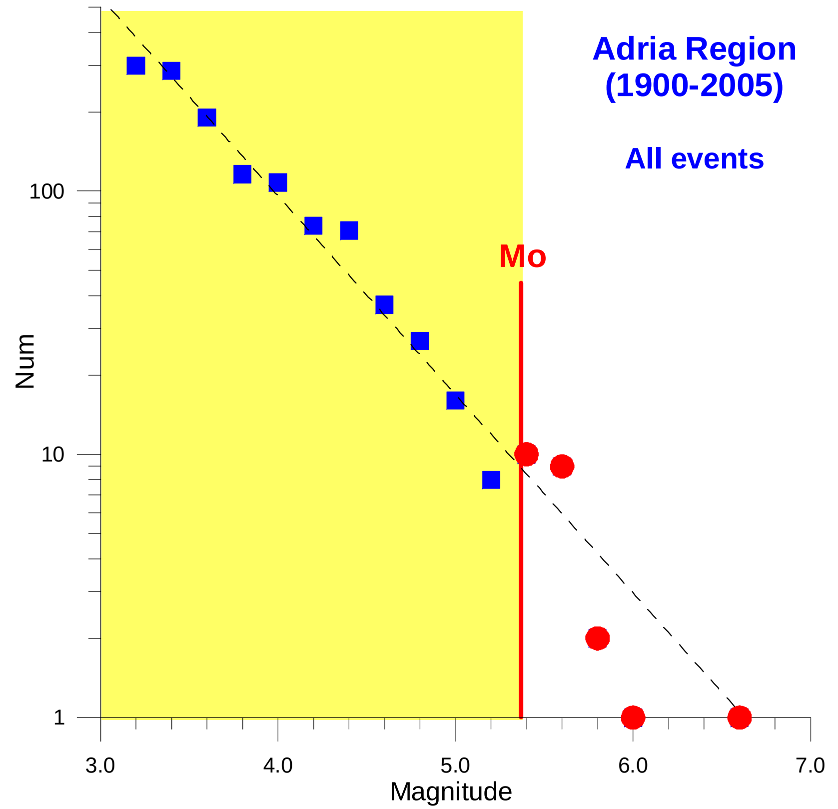
- $M_o - \Delta M \geq M_c$ where $\Delta M \approx 3$
- Yearly average number of events with $M \geq M_c$ must be>3

Magnitude threshold M_o:

- M_o corresponds to a minimum of N(M)
- The return period for events with $M \geq M_o$ is $\approx$6-7 years

➡ 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.

Choice of M_o

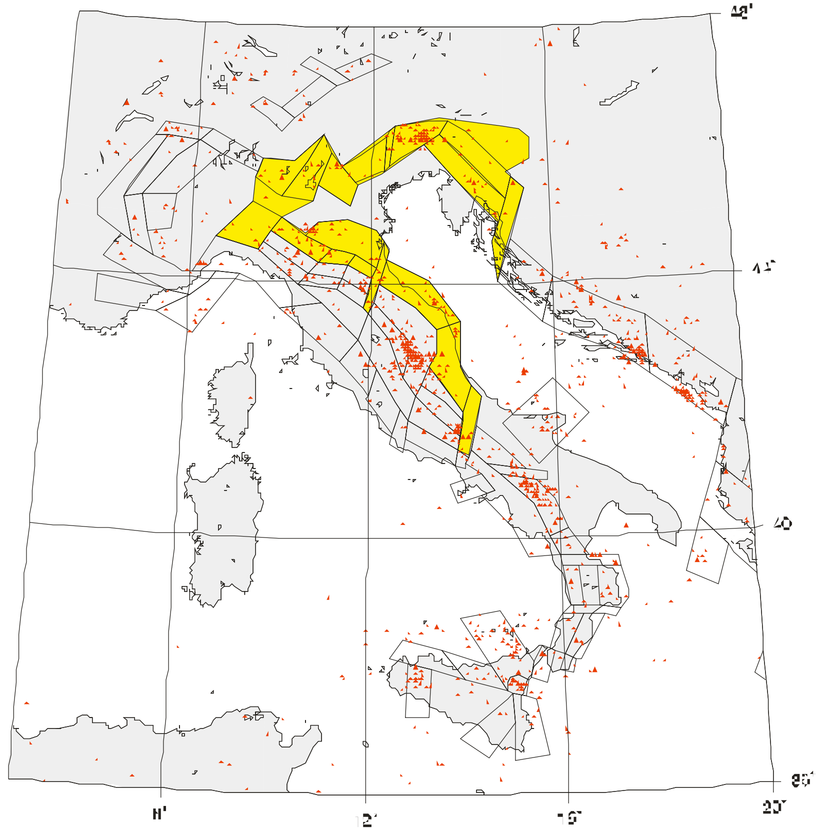


M_o=5.4 (17 events)

Return Period: about 6 years

Intermediate-term middle-range earthquake prediction CN

NORTHERN REGION



Prediction of the events with M≥5.4

Updated to 1-5-2007

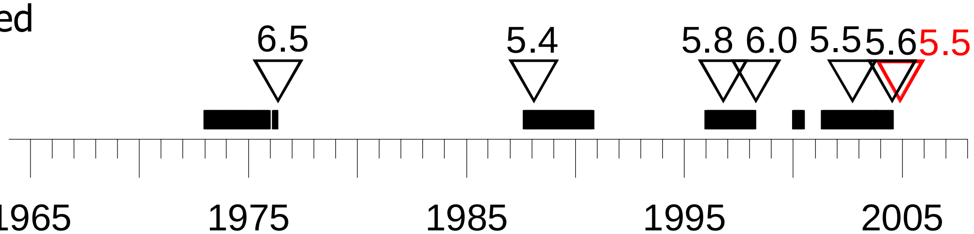
(next update: 1-7-2007)

TIP: 29.2% of total time

TIPs

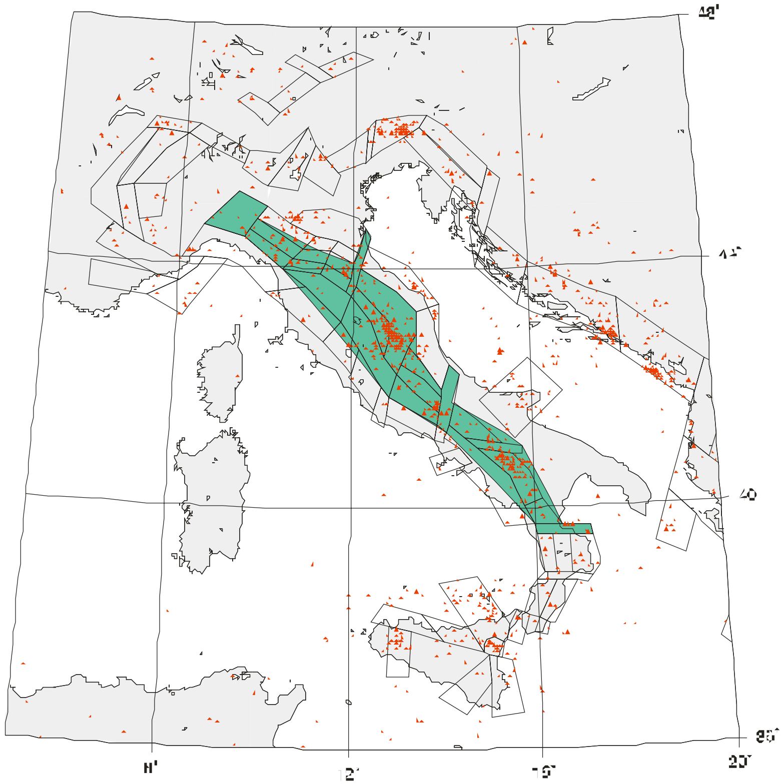
Strong Earthquakes predicted

Failure to predict



Intermediate-term middle-range earthquake prediction CN

CENTRAL REGION

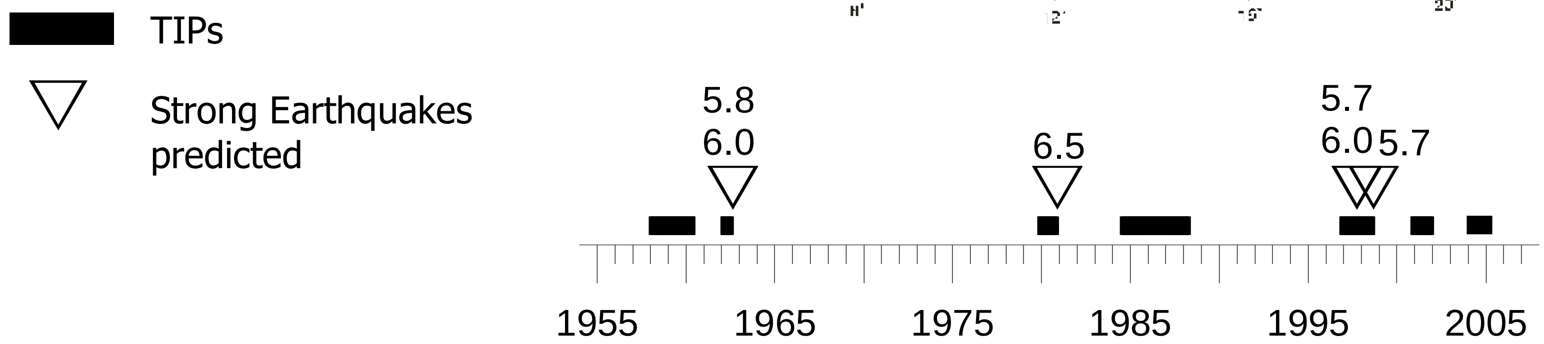


Prediction of the events with M≥5.6

Updated to 1-5-2007

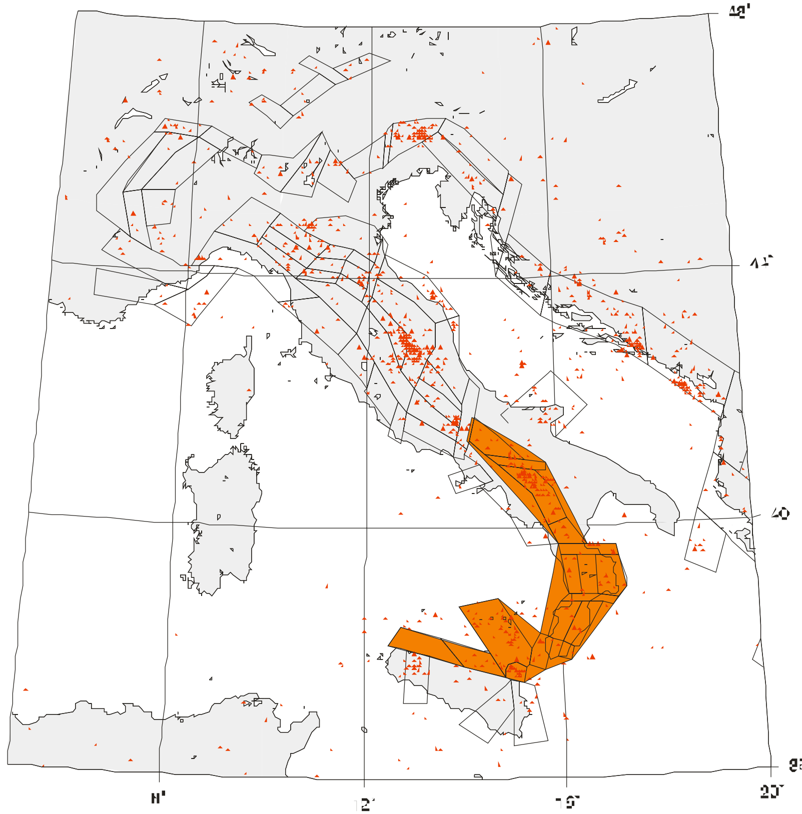
(next update: 1-7-2007)

TIP: 22.4% of total time



Intermediate-term middle-range earthquake prediction CN

SOUTHERN REGION



Prediction of the events with M≥5.6

Updated to 1-5-2007

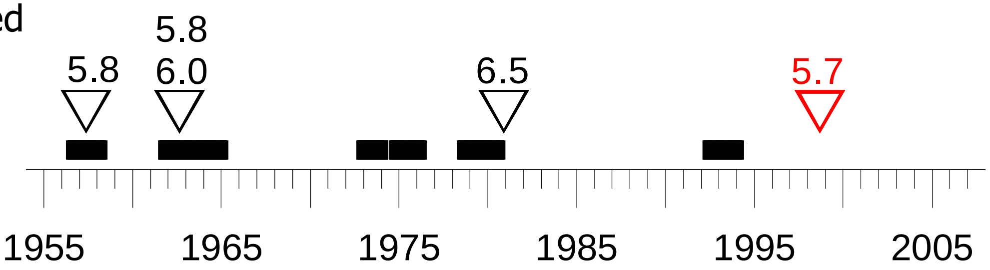
(next update: 1-7-2007)

TIP: 27.5% of total time

TIPs

Strong Earthquakes predicted

Failure to predict



Intermediate-term middle-range earthquake prediction

Space-time volume of alarm in CN application in Italy

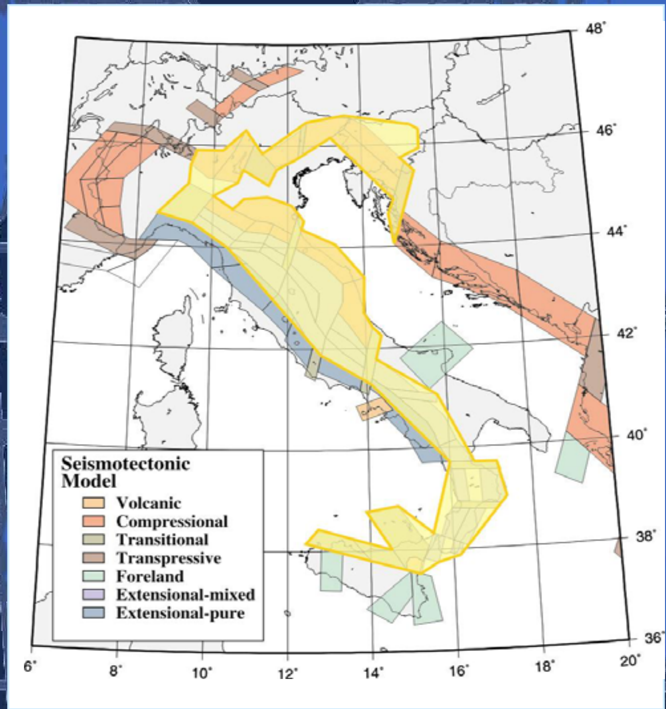
Experiment	Space-time volume of alarm (%)	n/N	Confidence level (%)
Retrospective* (1954 – 1963)	41	3/3	93
Retrospective (1964 – 1997)	27	5/5	>99
Forward (1998 – 2007)	36	4/5	94
All together (1954 – 2007)	31	12/13	>99

* Central and Southern regions only

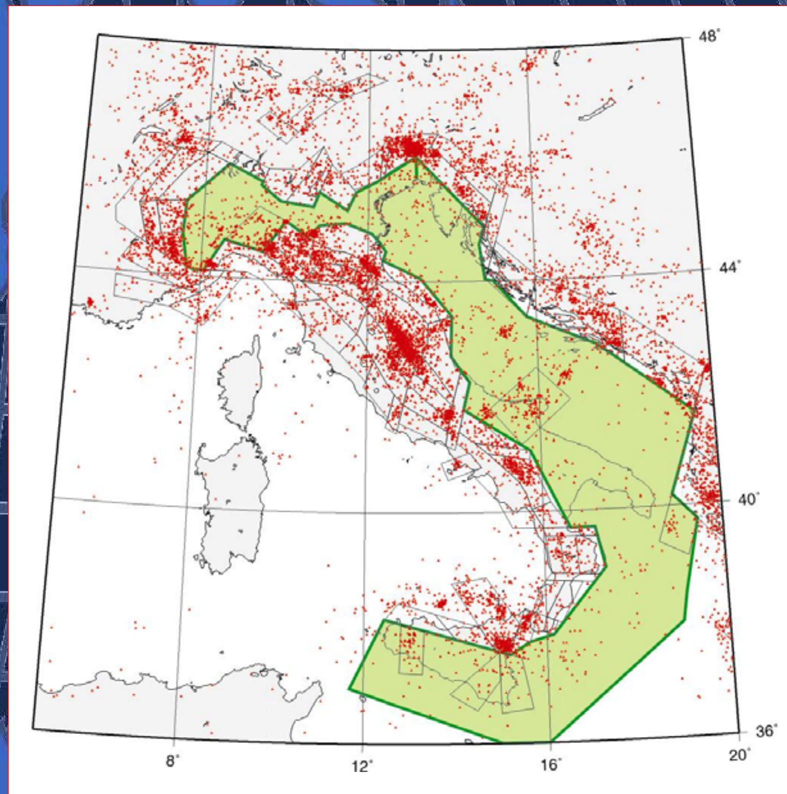
Algorithm CN predicted 12 out of the 13 strong earthquakes occurred in the monitored zones of Italy, with 31% of the considered space-time volume occupied by alarms.

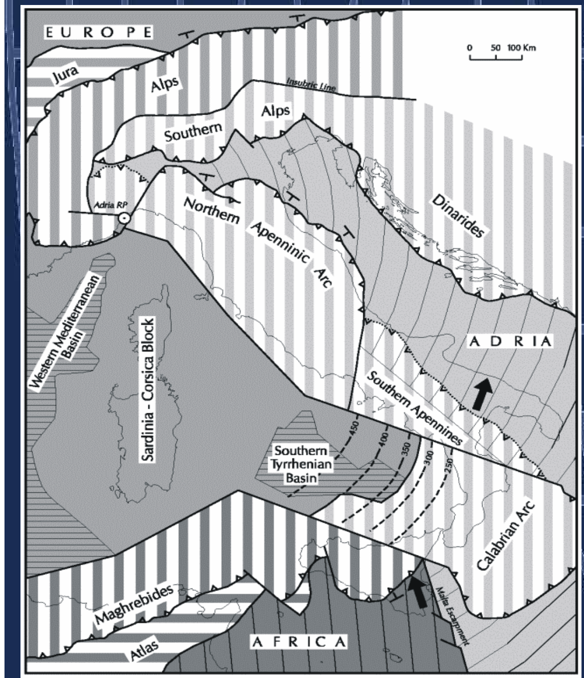
(updated to May 1 2007)

Adriatic Region



CN region





(Meletti et al., Pageoph, 2000)

CN application to the Adriatic region

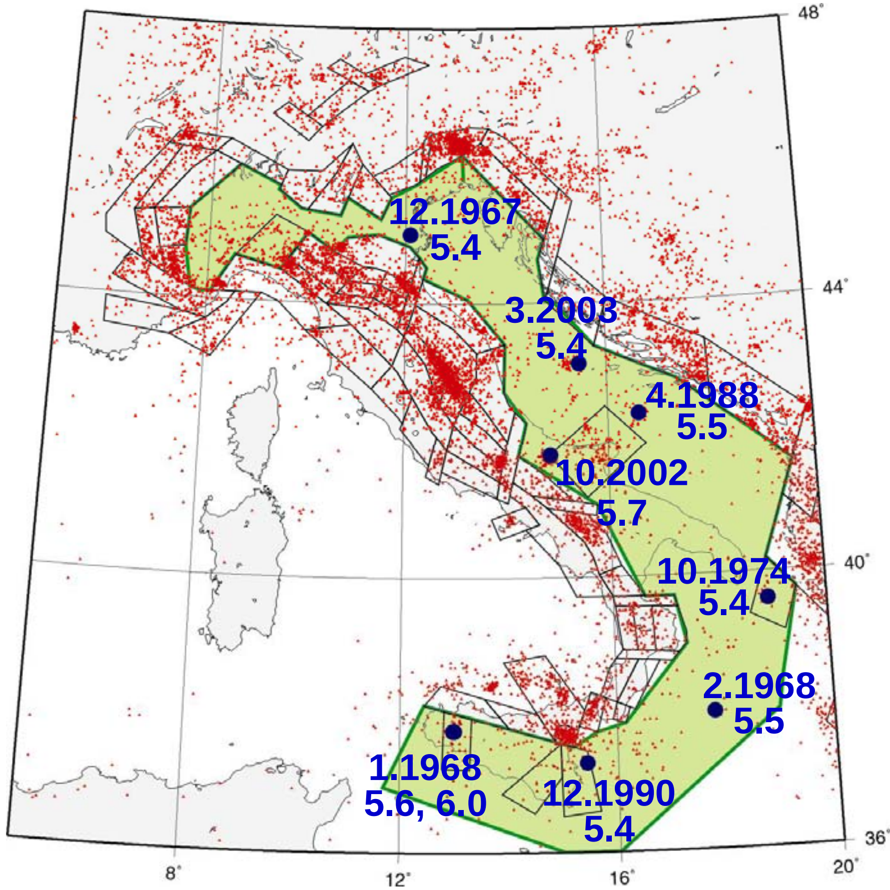
ADRIA REGION

Prediction of the events with M≥5.4

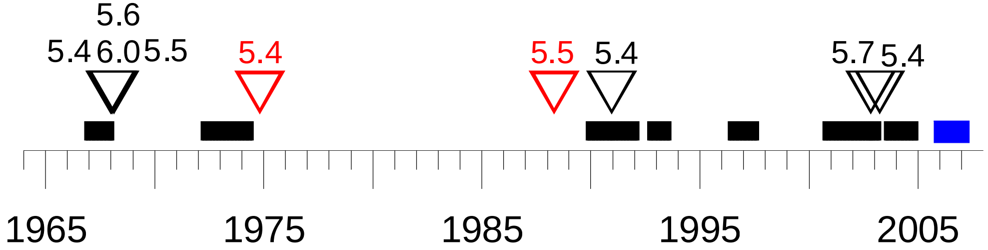
UCI catalog

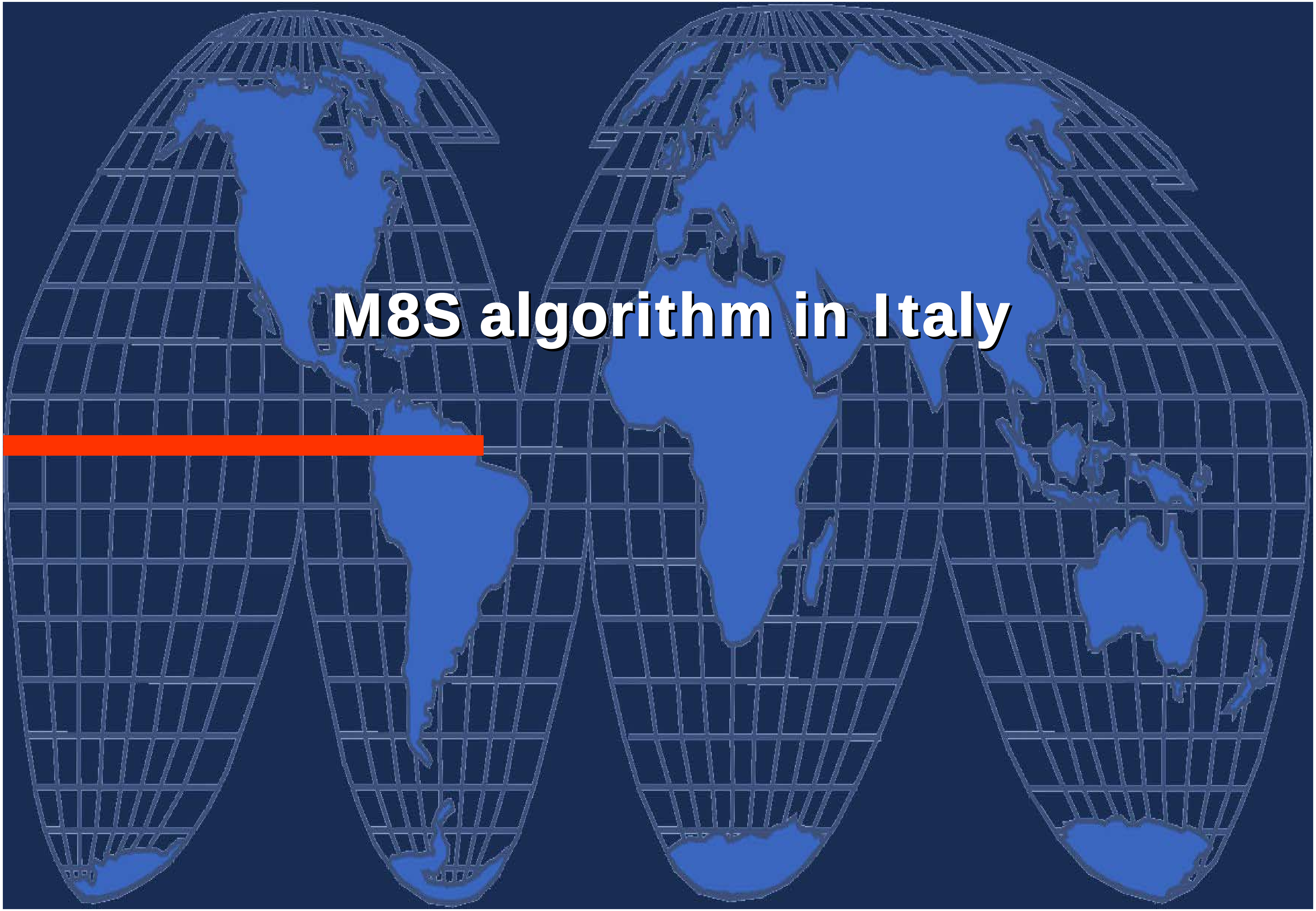
Updated to 1-5-2007
(next update: 1-7-2007)
TSP: 1.1 1999

78 % predicted events (7 out of 9)
TIP: 29.9 % of total time
5 false alarms



TIPs
Strong Earthquakes predicted
Failure to predict





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 new 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

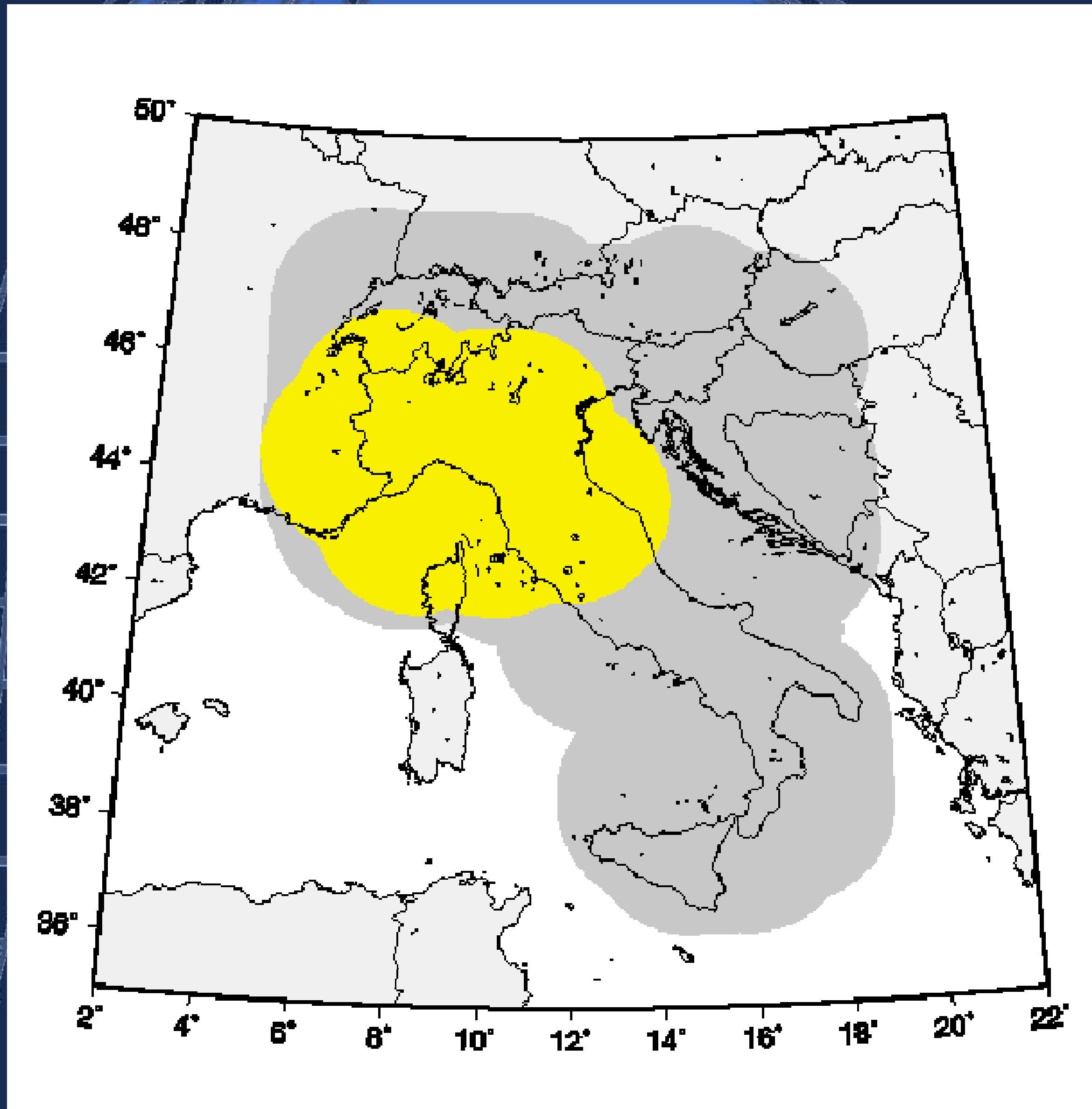
Magnitude:
M≥ 6.5

Radius of CI:
192 Km

Monitored region

Alerted region

Predictions as on: 1-7-2004



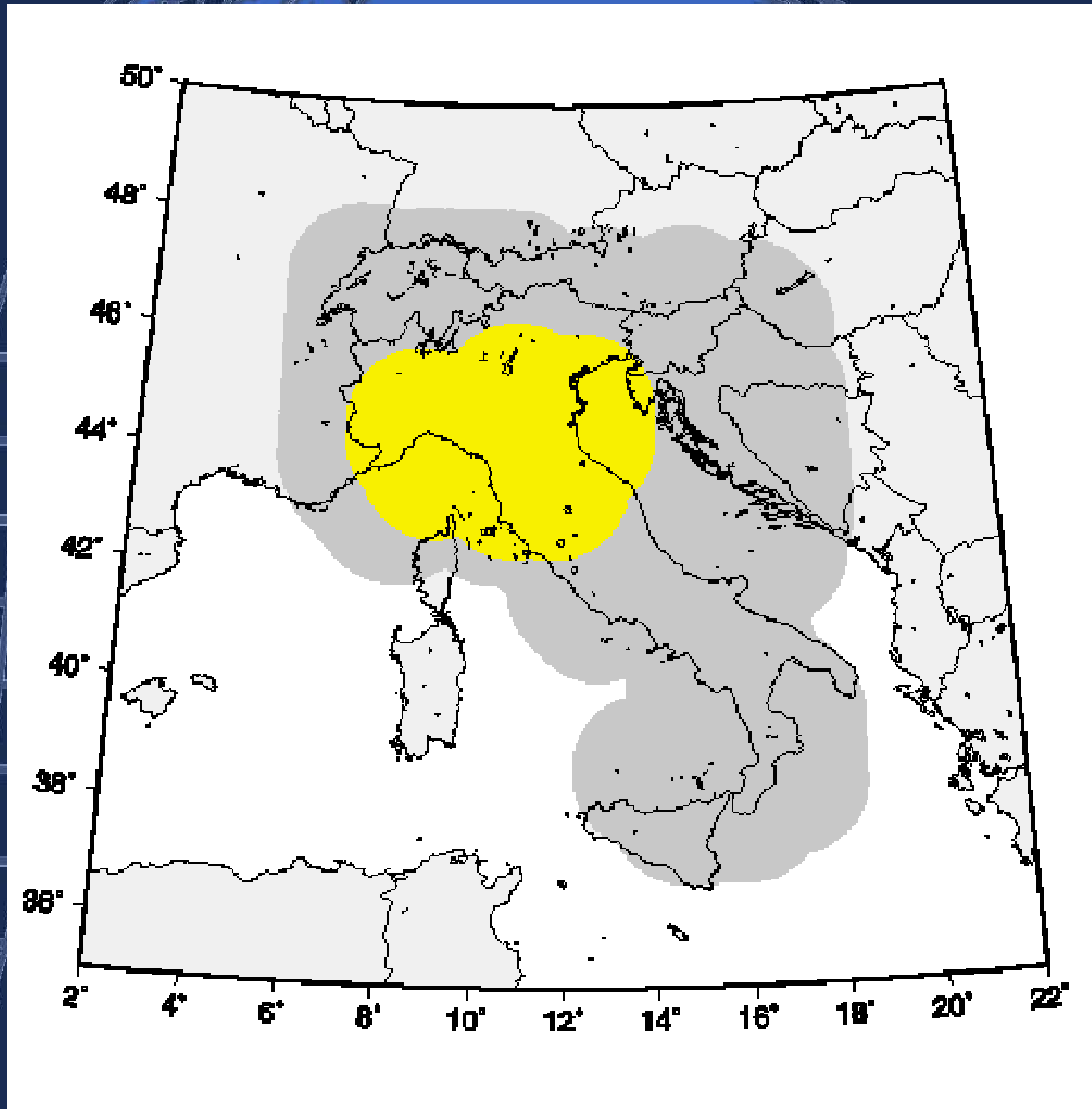
M8S algorithm in Italy

Magnitude:
M≥ 6.0

Radius of CI:
138 Km

Monitored region

Alerted region



Predictions as on: 1-7-2004

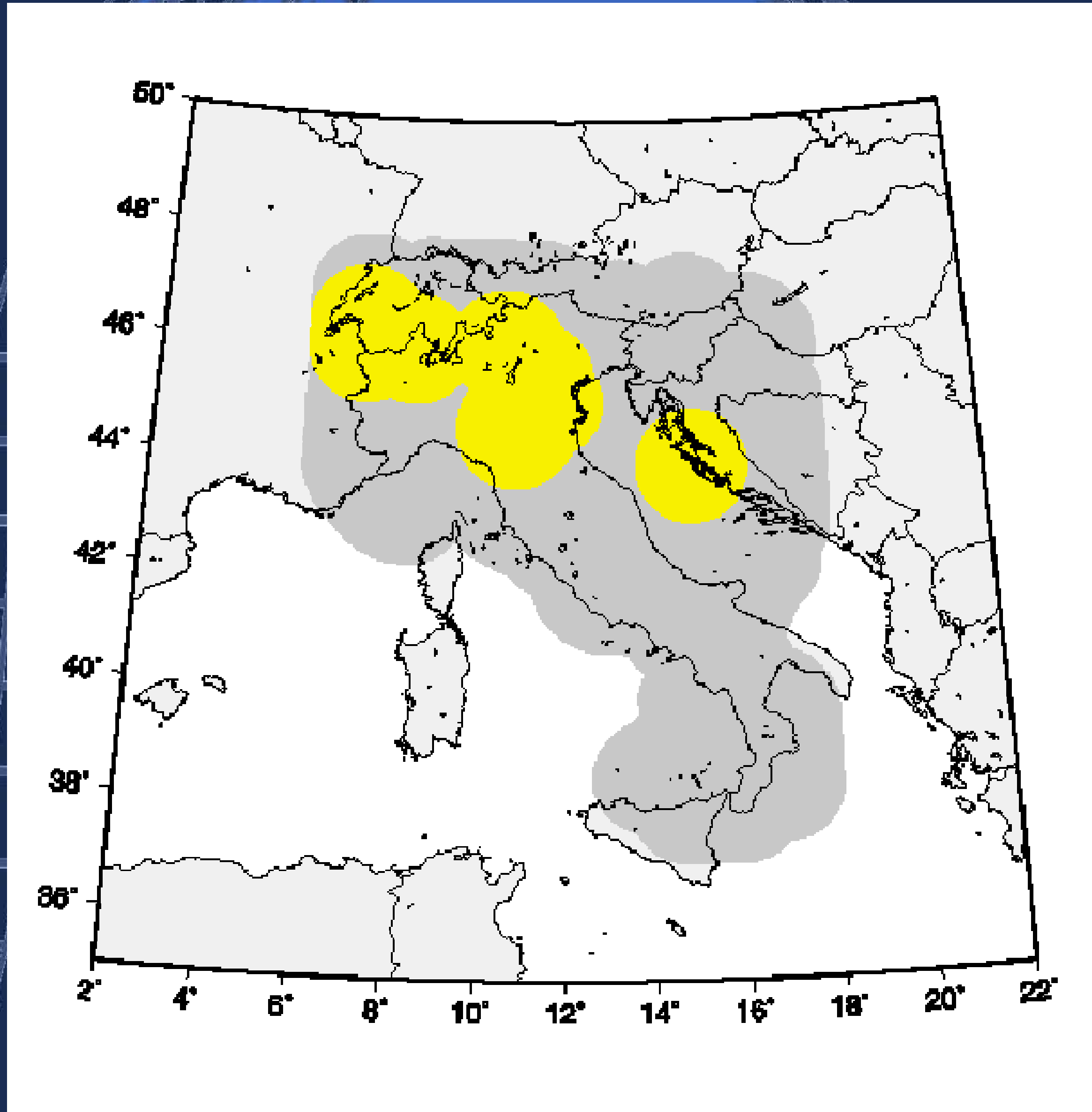
M8S algorithm in Italy

Magnitude:
M≥ 5.5

Radius of CI:
106 Km

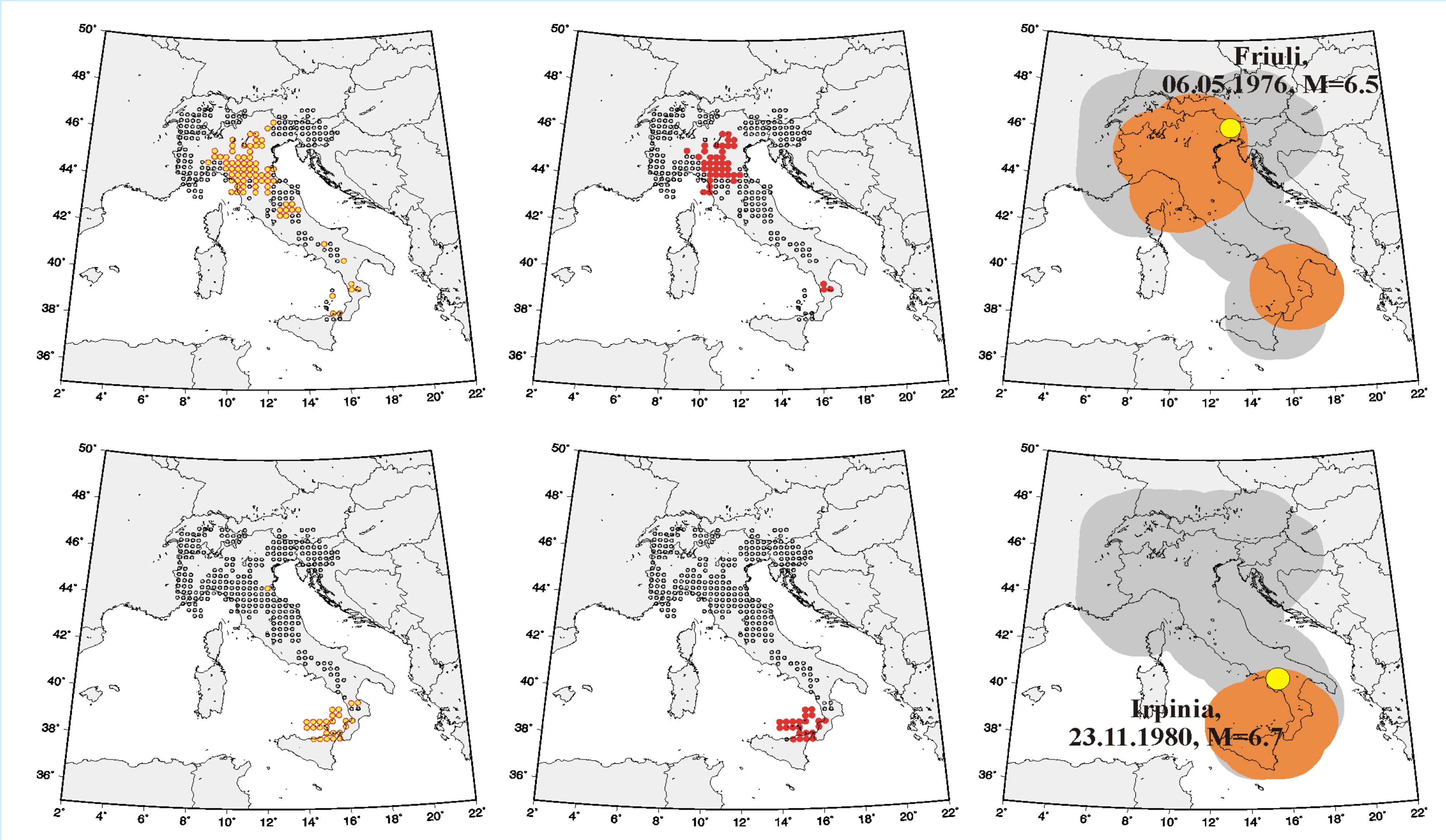
Monitored region

Alerted region



Predictions as on: 1-7-2004

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



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 (2002-2007)	49	0/0	43	0/0	25	5/9
All together (1972-2007)	37	2/2	40	1/2	38	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 about 97%; no estimation is yet possible for other magnitude levels.

(updated to January 1 2007)

Intermediate-term middle-range earthquake prediction experiment in Italy

CN algorithm (*Keilis-Borok et al., 1990; Peresan et al., 2005*)
M8S algorithm (*Kossobokov et al, 2002)*

Main features:

- Fully formalized algorithms and computer codes available for independent testing;
- Use of published & routine catalogues of earthquakes;
- Worldwide tests ongoing for more than 10 years permitted to assess the significance of the issued predictions (*Kossobokov et al., 1999; Rotwain and Novikova, 1999)*

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**

Intermediate-term middle-range earthquake prediction experiment in Italy

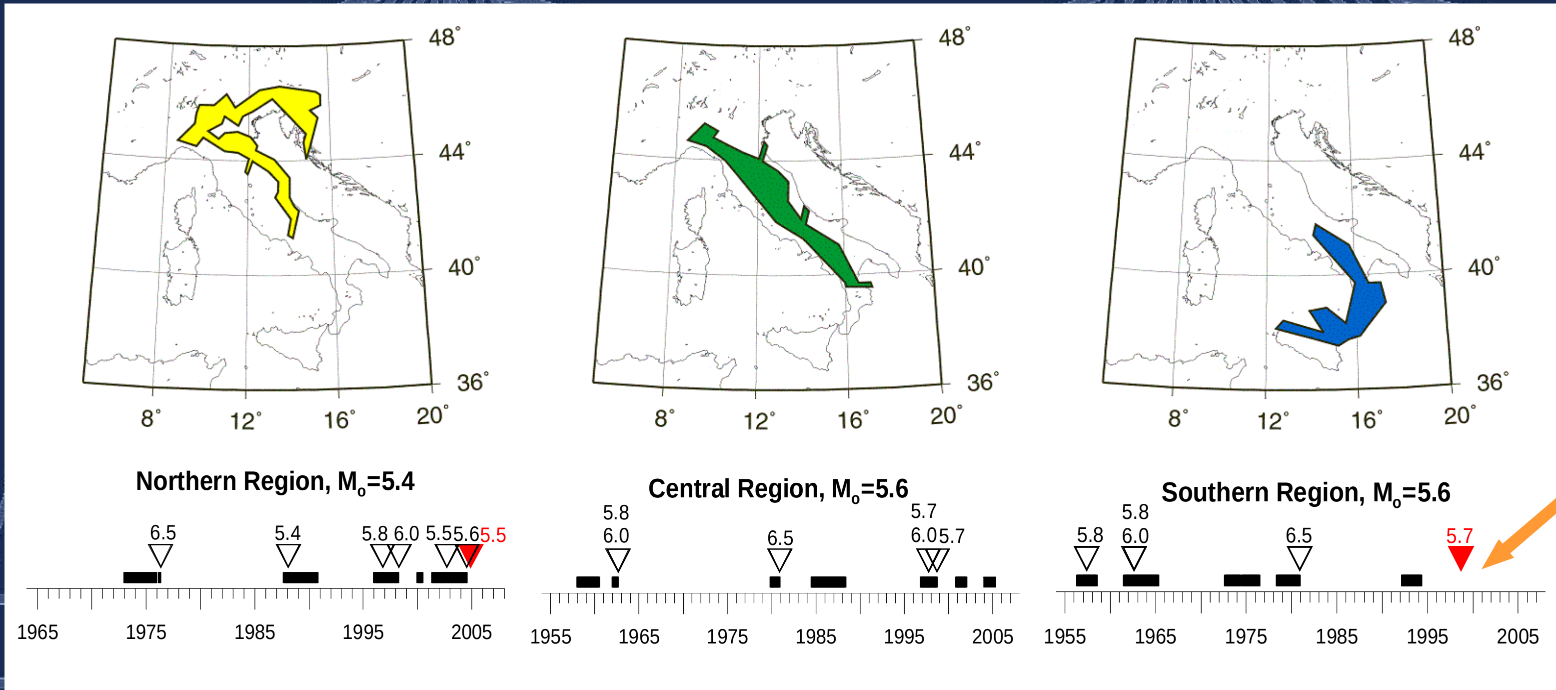
Prediction experiment: launched starting on July 2003, is aimed at a *real-time test* of CN and M8S predictions in Italy.

Updated predictions are regularly posted at:

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

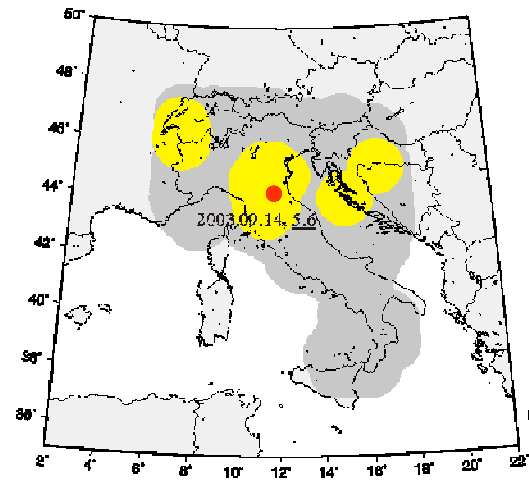
A complete archive of predictions is made accessible to a number of scientists, with the goal to accumulate a collection of correct and wrong predictions, that will permit to validate the considered methodology.

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.

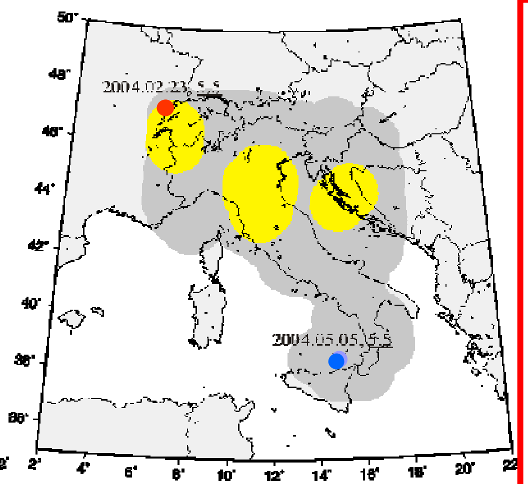


CN algorithm

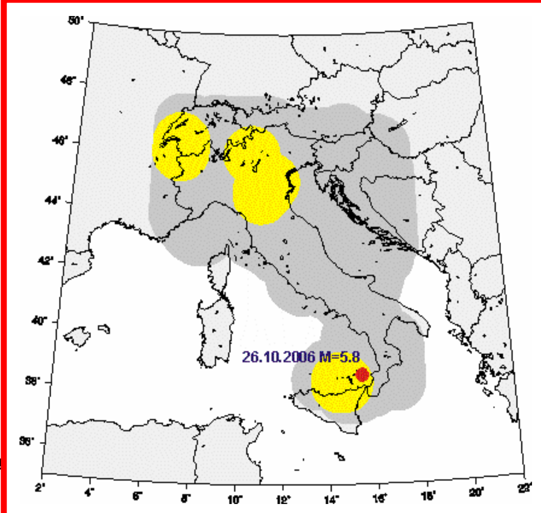
Times of Increased Probability for the occurrence of events with M>Mo within the monitored regions



2003.5-2004



2004-2004.5



2006.5-2007

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

M8S algorithm

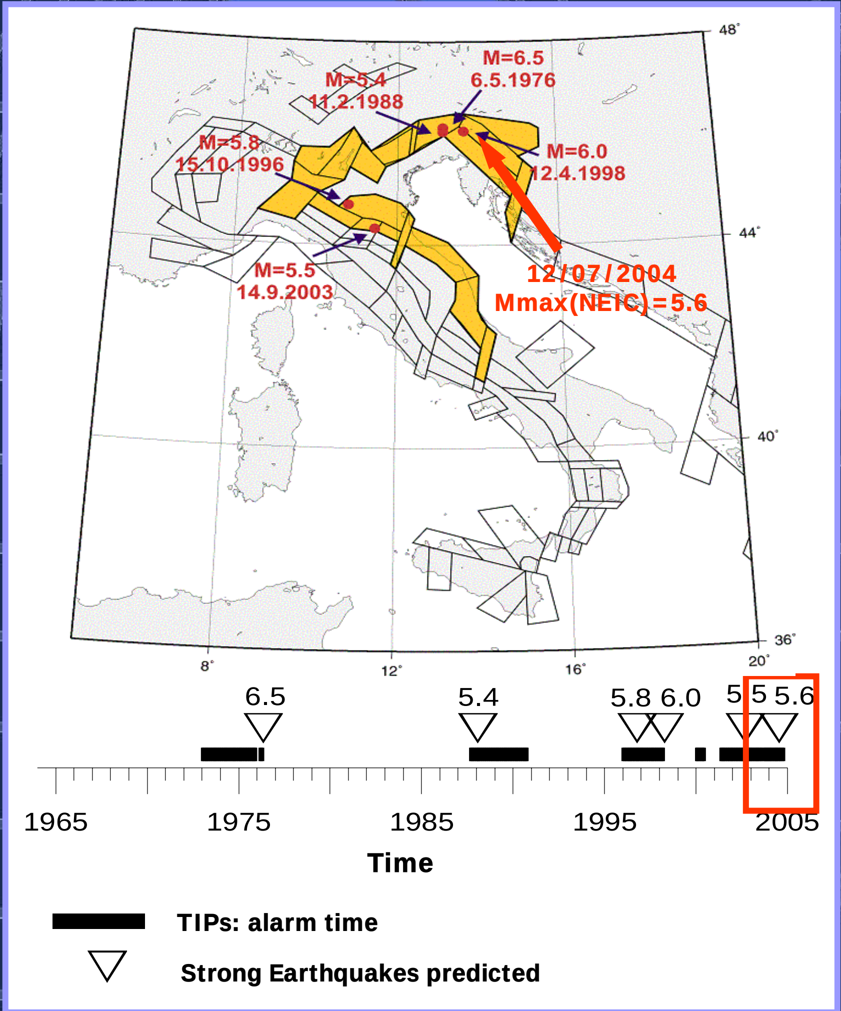
Monitored region

Alerted region

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

Updated to March 1 2007

The CN real-time monitoring of seismic flow



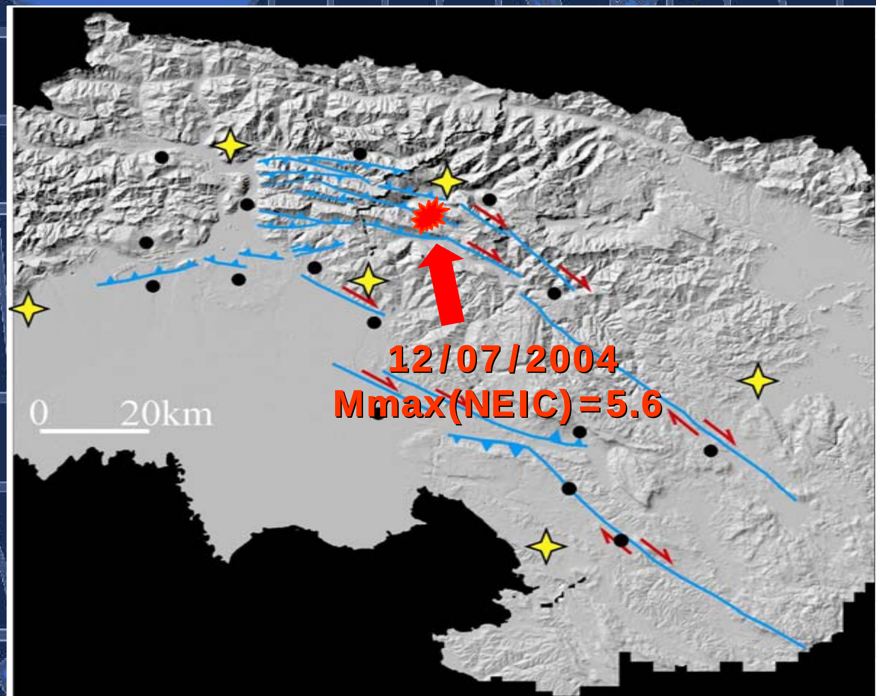
The Bovec earthquake - July 12 2004

Alarmed area for M≥5.4 by CN algorithm

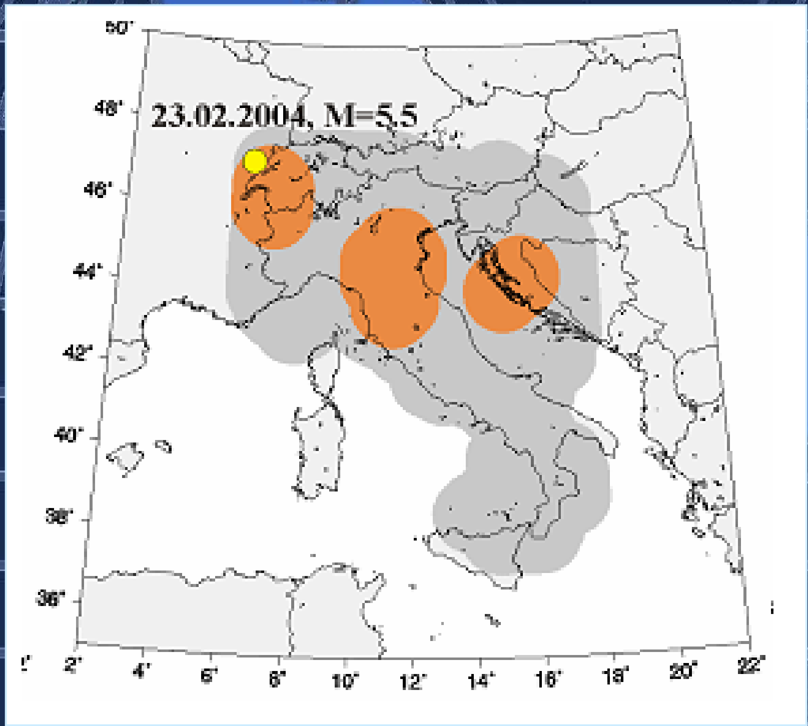
(Peresan et al., ESR,2005)

(As on 1 July 2004)

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



The M8S real-time monitoring of seismic flow



The Switzerland earthquake
February 23 2004

Alarmed area for M≥5.5 by M8S algorithm

(Peresan et al., ESR,2005)

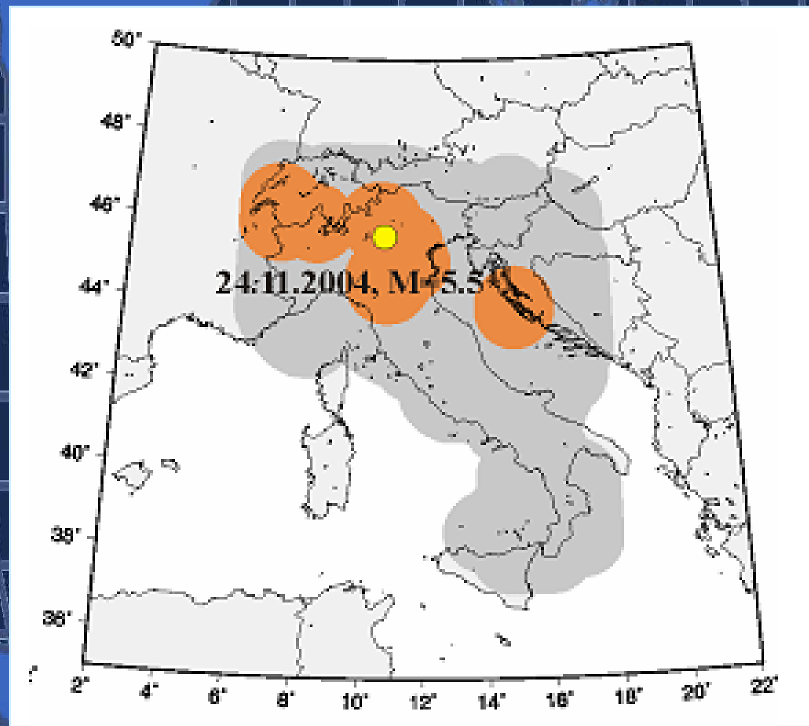
(As on 1 January – 1 July 2004)

The Salò earthquake
November 24 2004

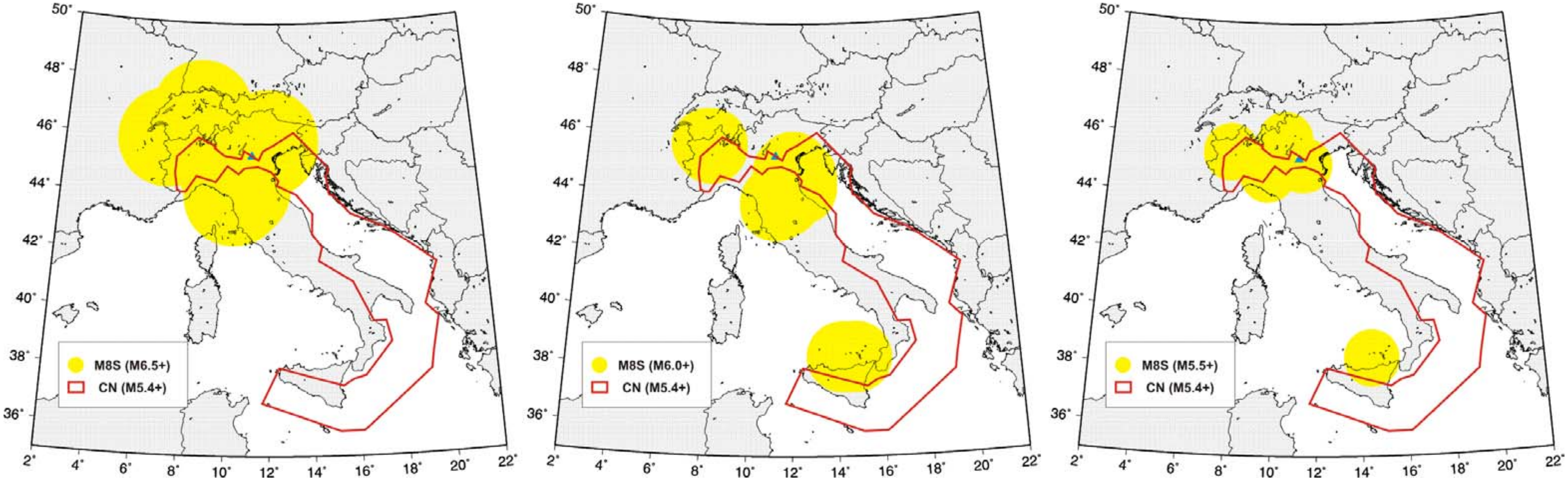
Alarmed area for M≥5.5 by M8S algorithm

Peresan et al., ESR,2005)

(As on 1 July 2004 – 1 January 2005)



The current situation of alarms (since January 2007)



Alarmed areas by:

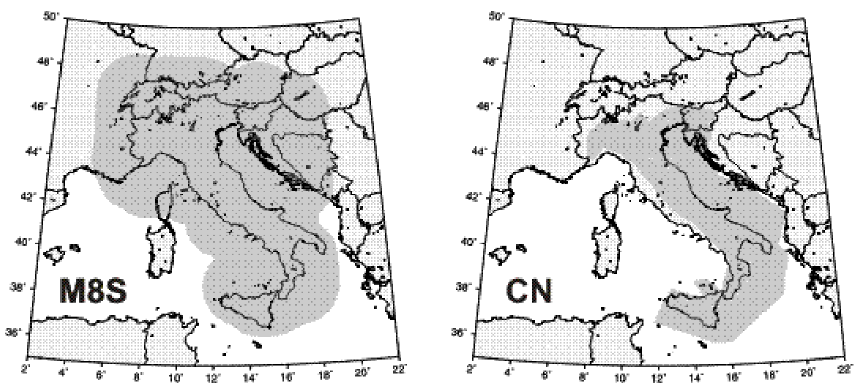
- M8S algorithm for M5.5+, M6.0+, M6.5+
- CN algorithm for M≥5.4

(Peresan , Kossobokov, Romashkova, Panza 2005, Earth Science Reviews, 69)

Current predictions are accessible (via password)

at the following web site:

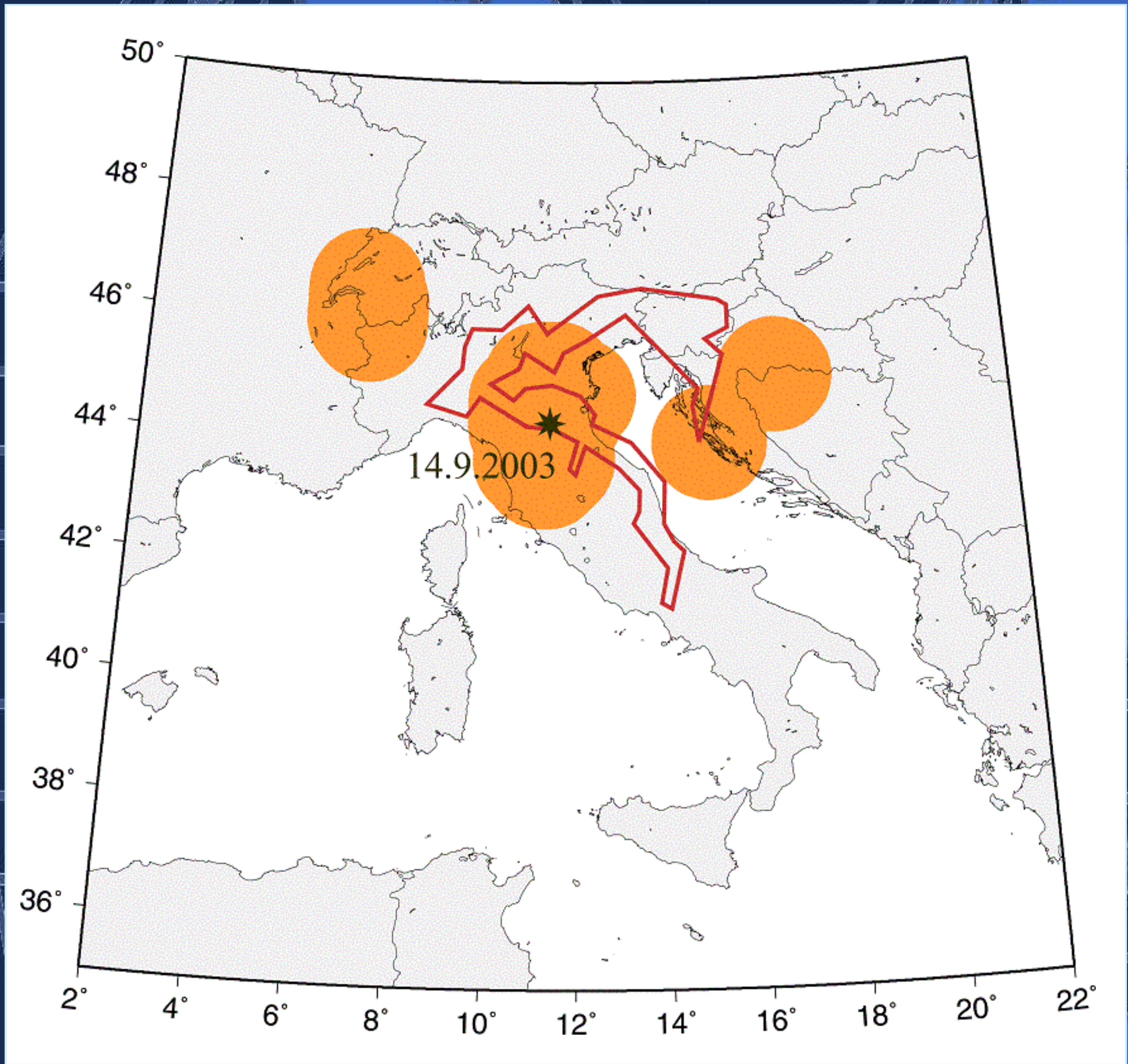
http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm



Monitored territory

(Subject to update on 1 July 2007)

Integrating CN and M8s prediction results

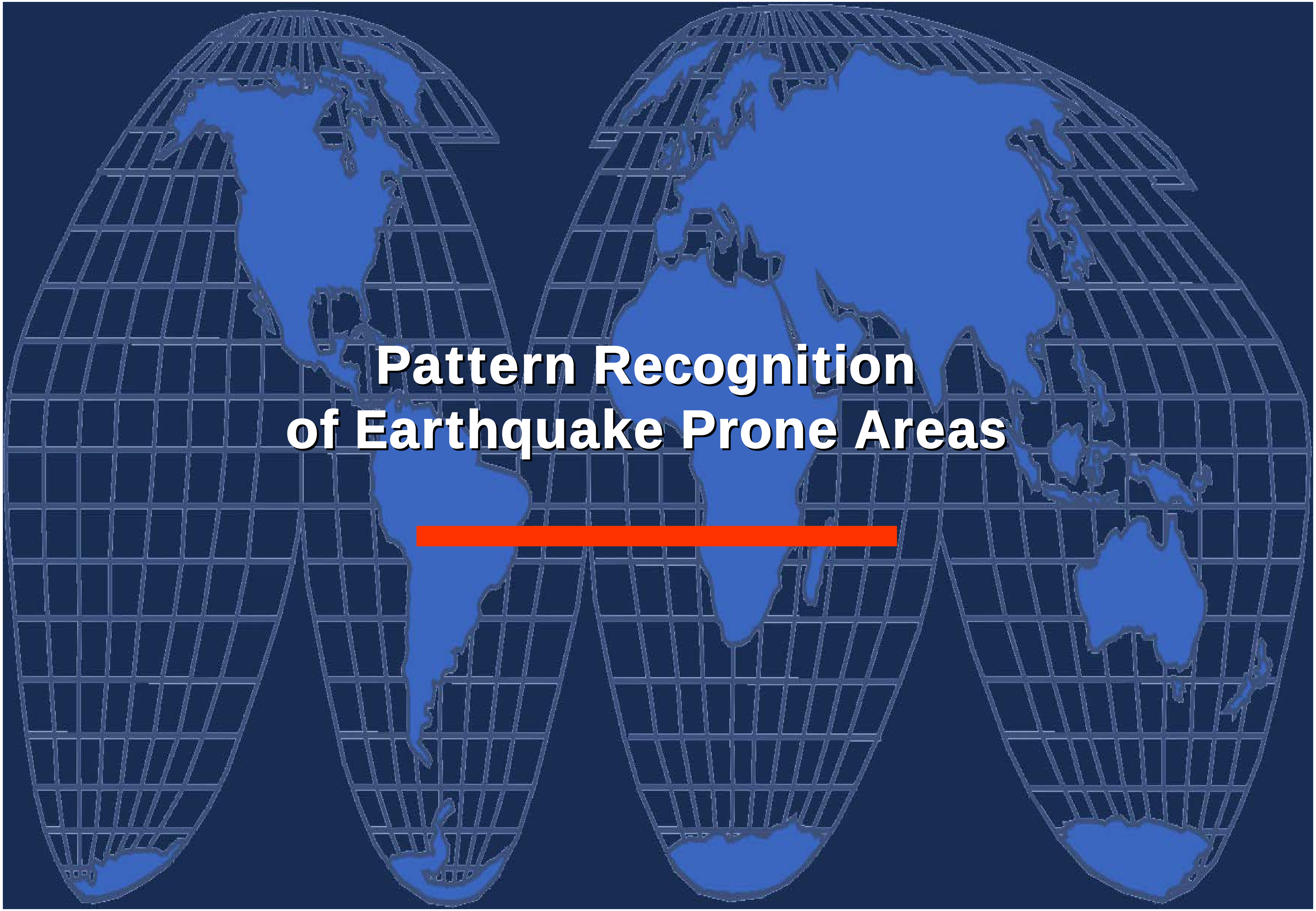


- 5 out of the 8 events with M ≥5.5, common to the 2 experiments (CN and M8s), are predicted by alarms declared by both algorithms.
- Space-time volume occupied by alarms around 16%.
- Space uncertainty reduced to about 15% of the common monitored area.

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).

Pattern Recognition of Earthquake Prone Areas



Pattern Recognition of Earthquake Prone areas

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

Pattern Recognition of Earthquake Prone areas

The nodes are defined by the

Morphostructural Zonation Method

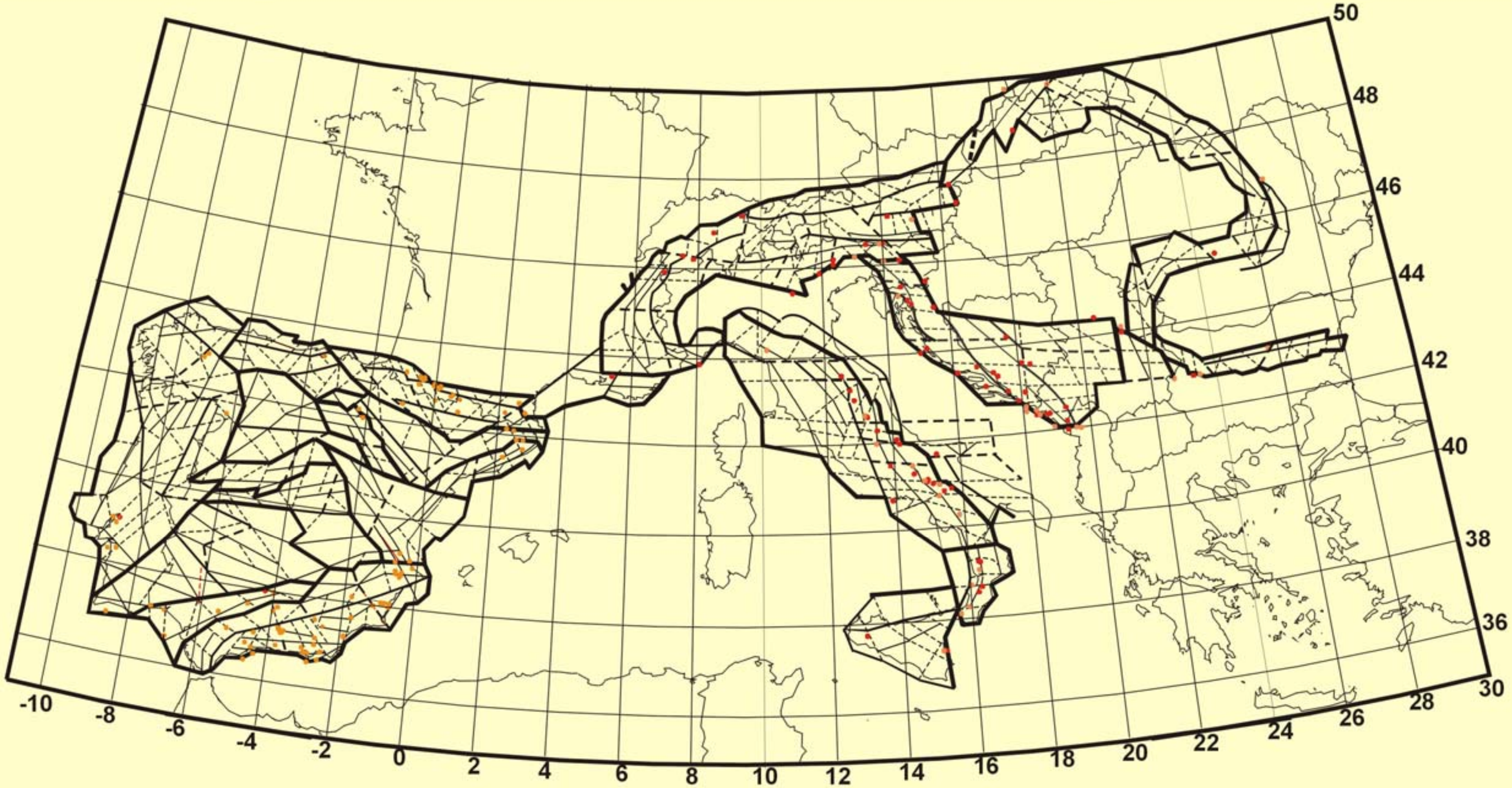
delineates a hierarchical block structure of the studied region, based on:

- topography
- tectonic data
- geological data

Pattern Recognition of Earthquake Prone areas

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

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



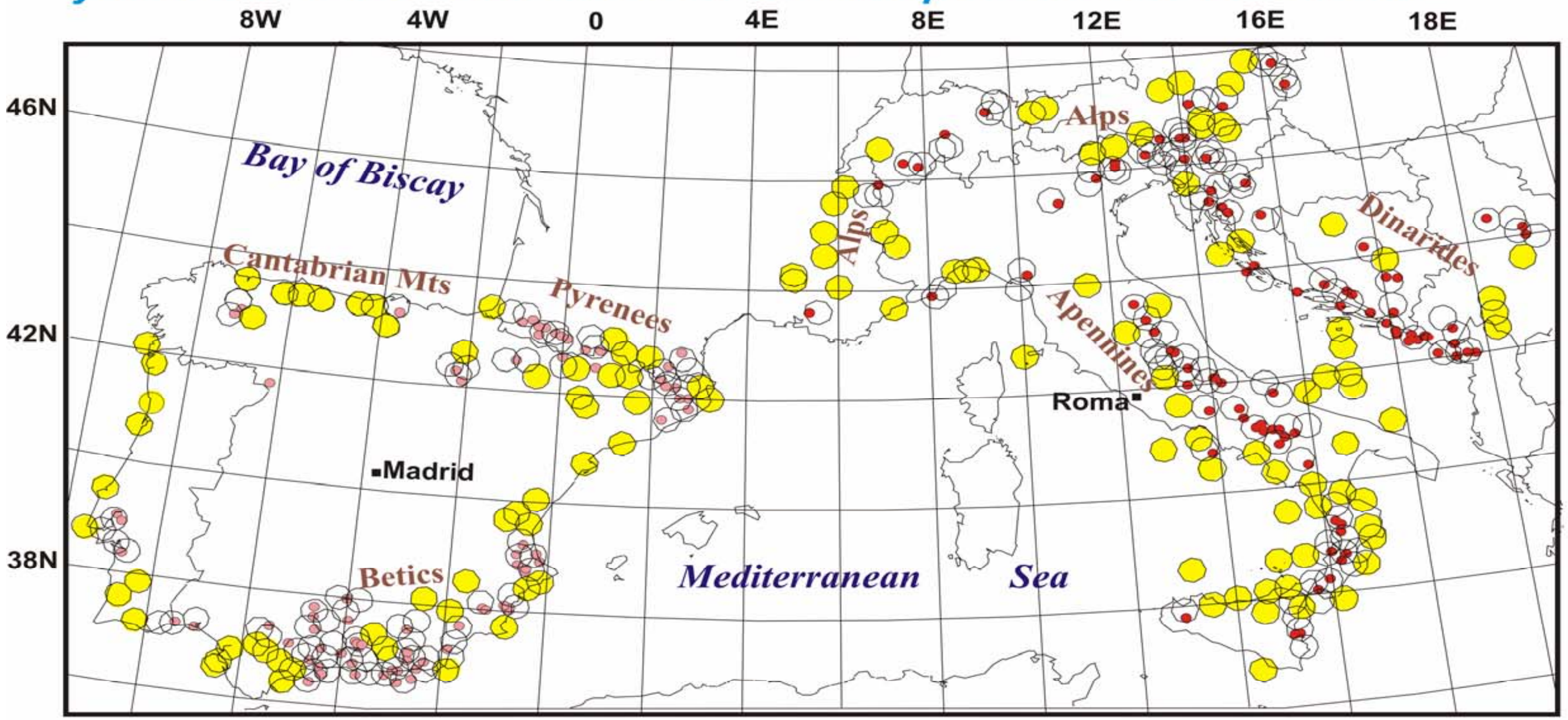
Morphostructural Zonation Map

Gorshkov et al. (2002, 2004)

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

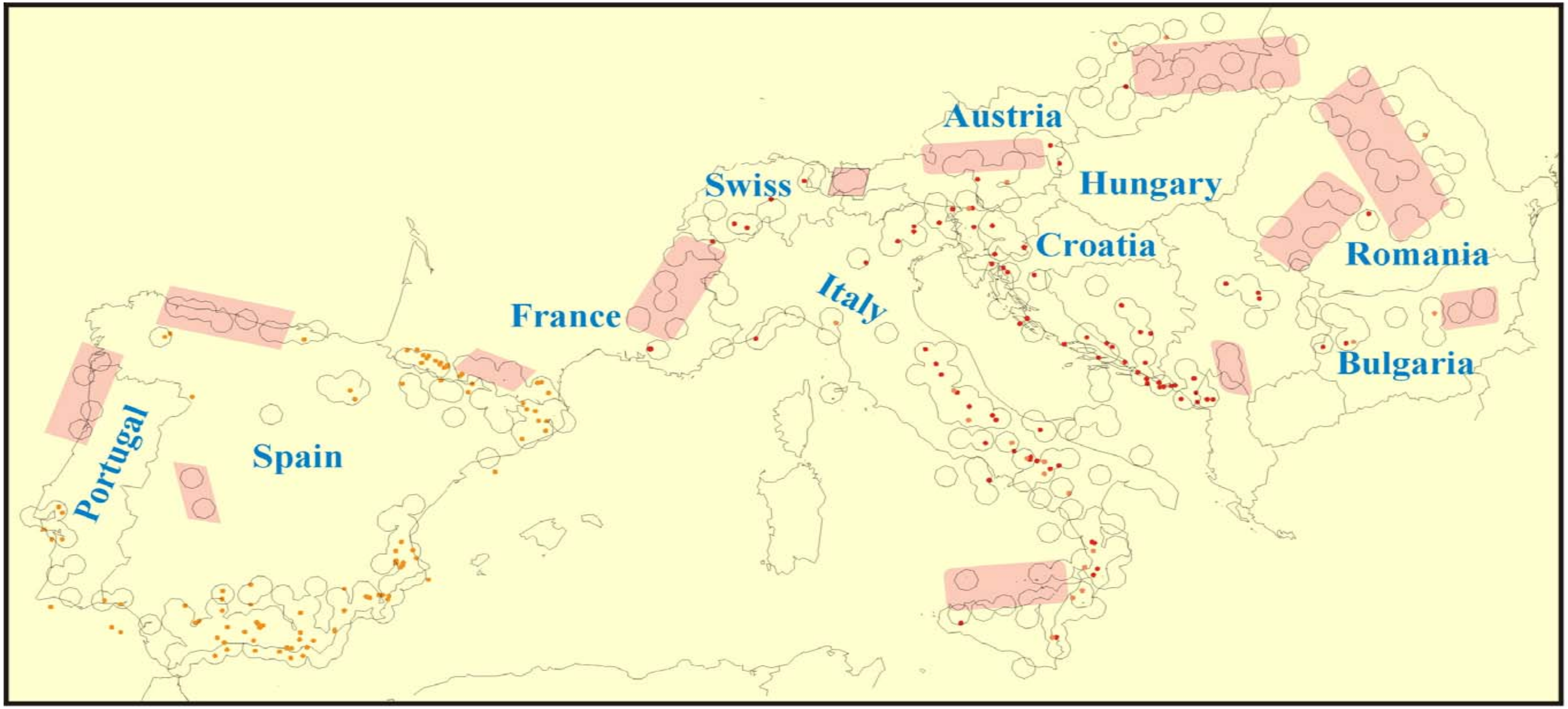
Target magnitudes: $M \geq 6.0$ - Alps, Apennines and Dinarides
$M \geq 5.0$ - Iberia

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



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

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



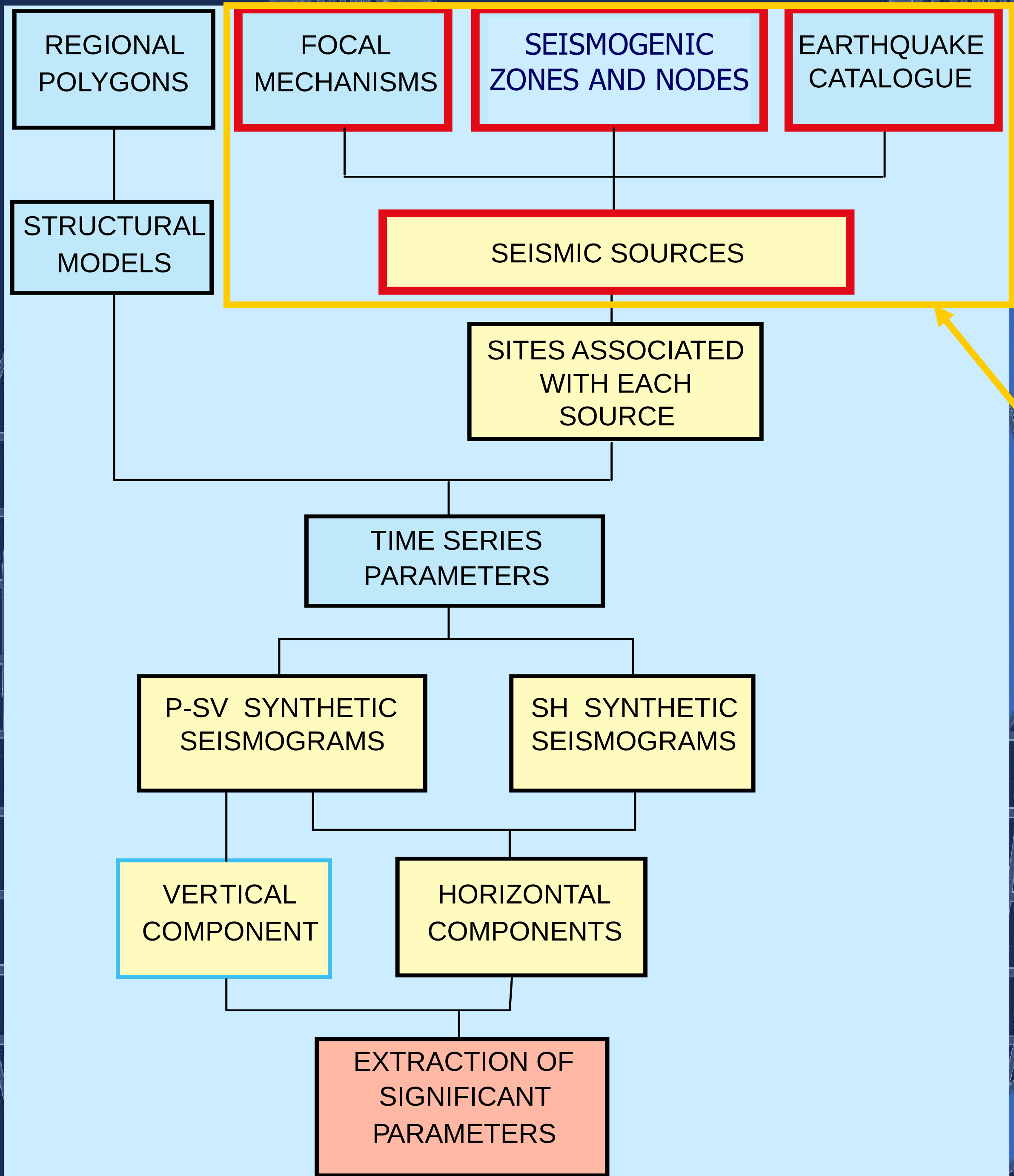
Multiscale Neo-deterministic Seismic Hazard Scenarios

Regional seismic hazard scenarios

(ground motion at bedrock)

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

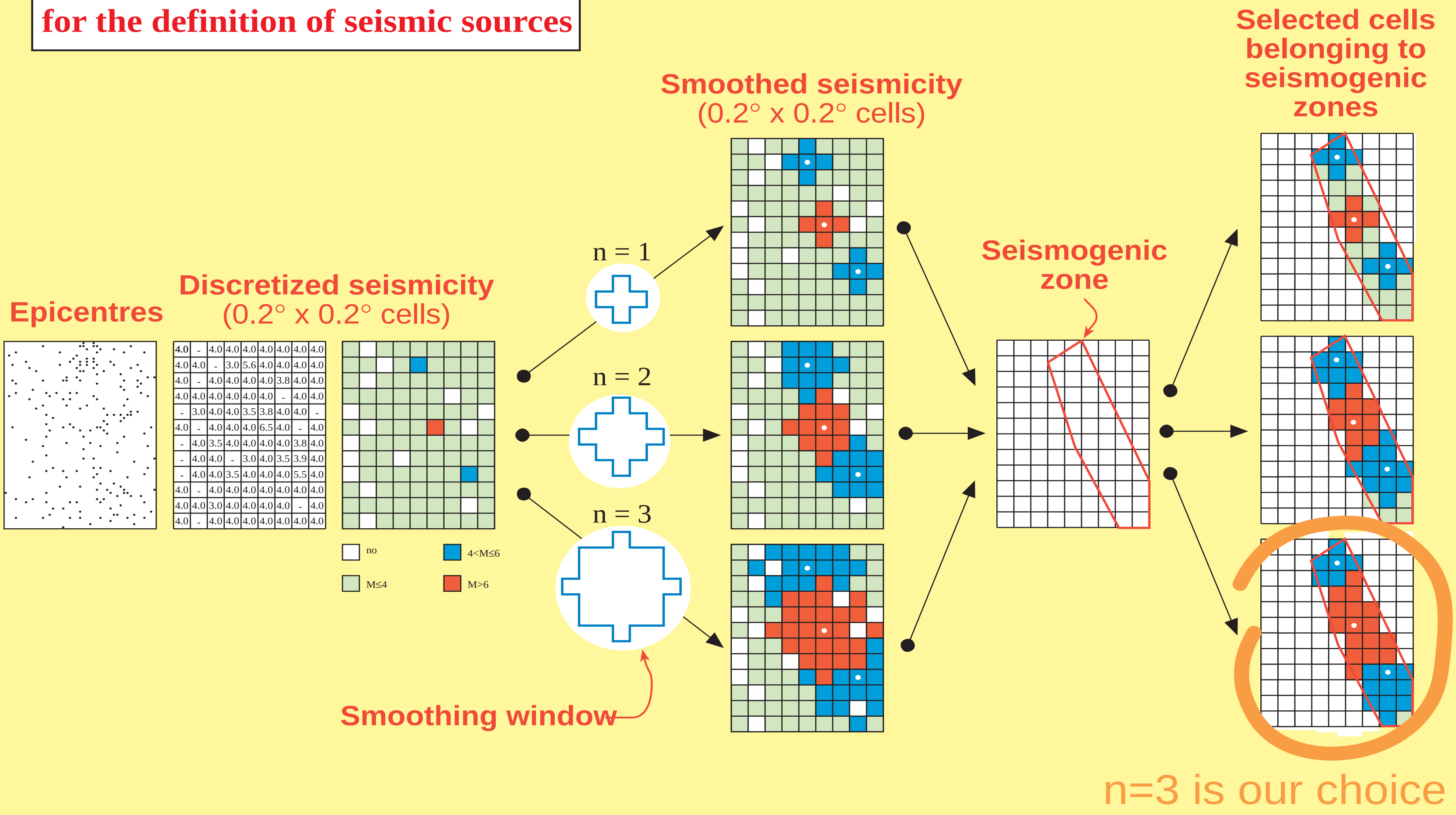
Flow-chart of the neo-deterministic hazard method

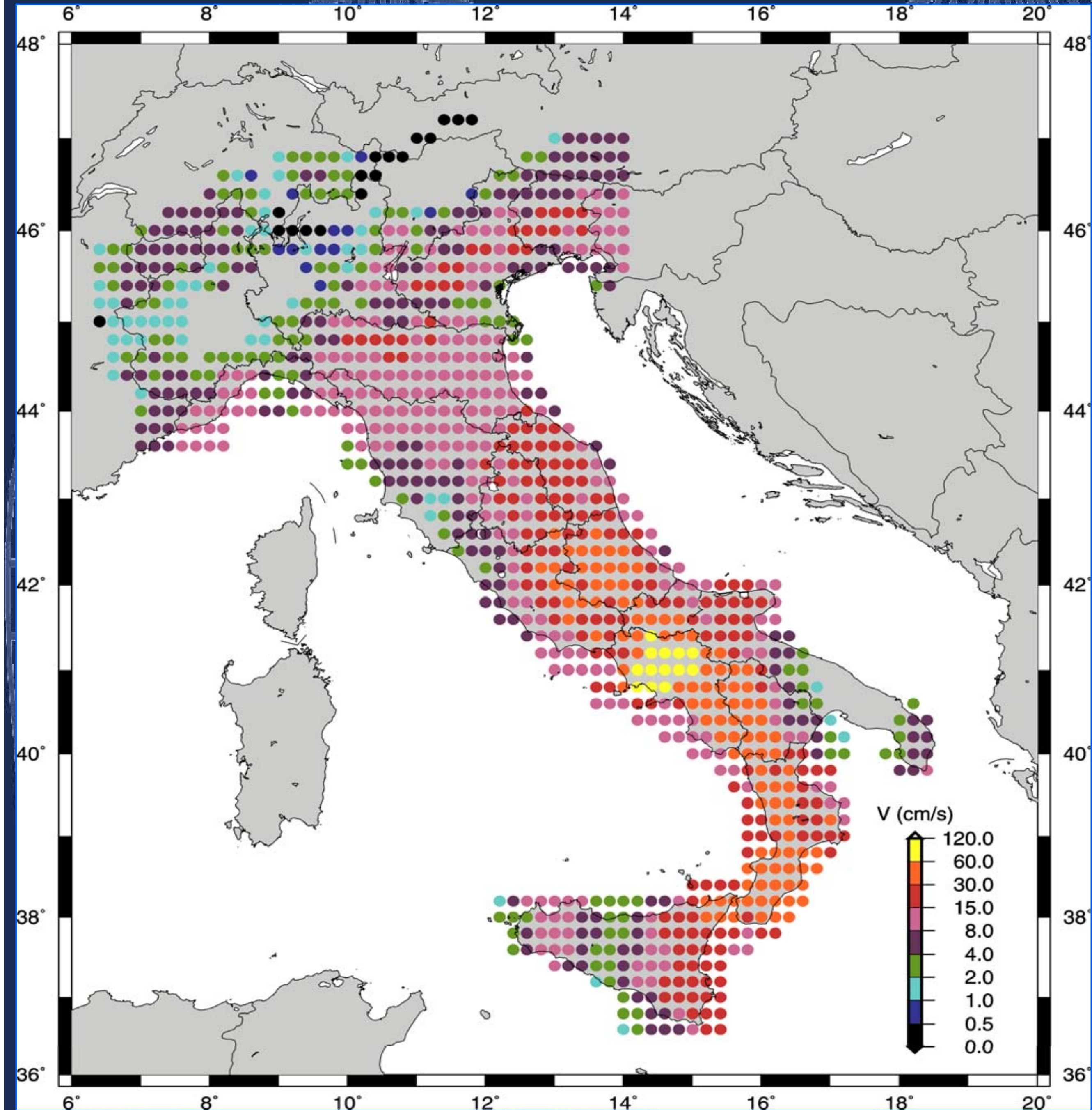


Seismic sources are defined based on seismic history, seismotectonic and seismogenic nodes.

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

SMOOTHING OF SEISMICITY
for the definition of seismic sources





Deterministic hazard scenarios at national scale

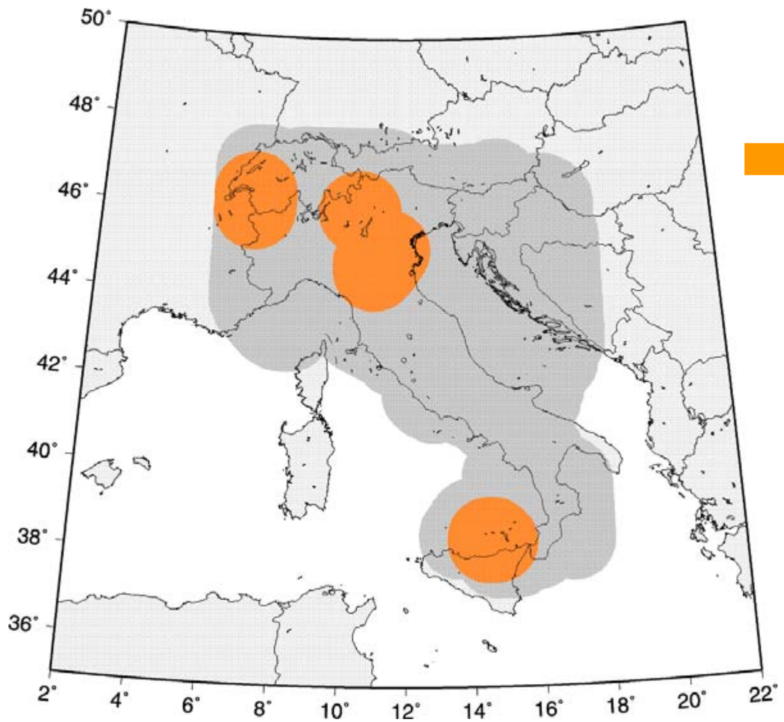
PGV: Maximum estimated velocity

Scenarios at bedrock

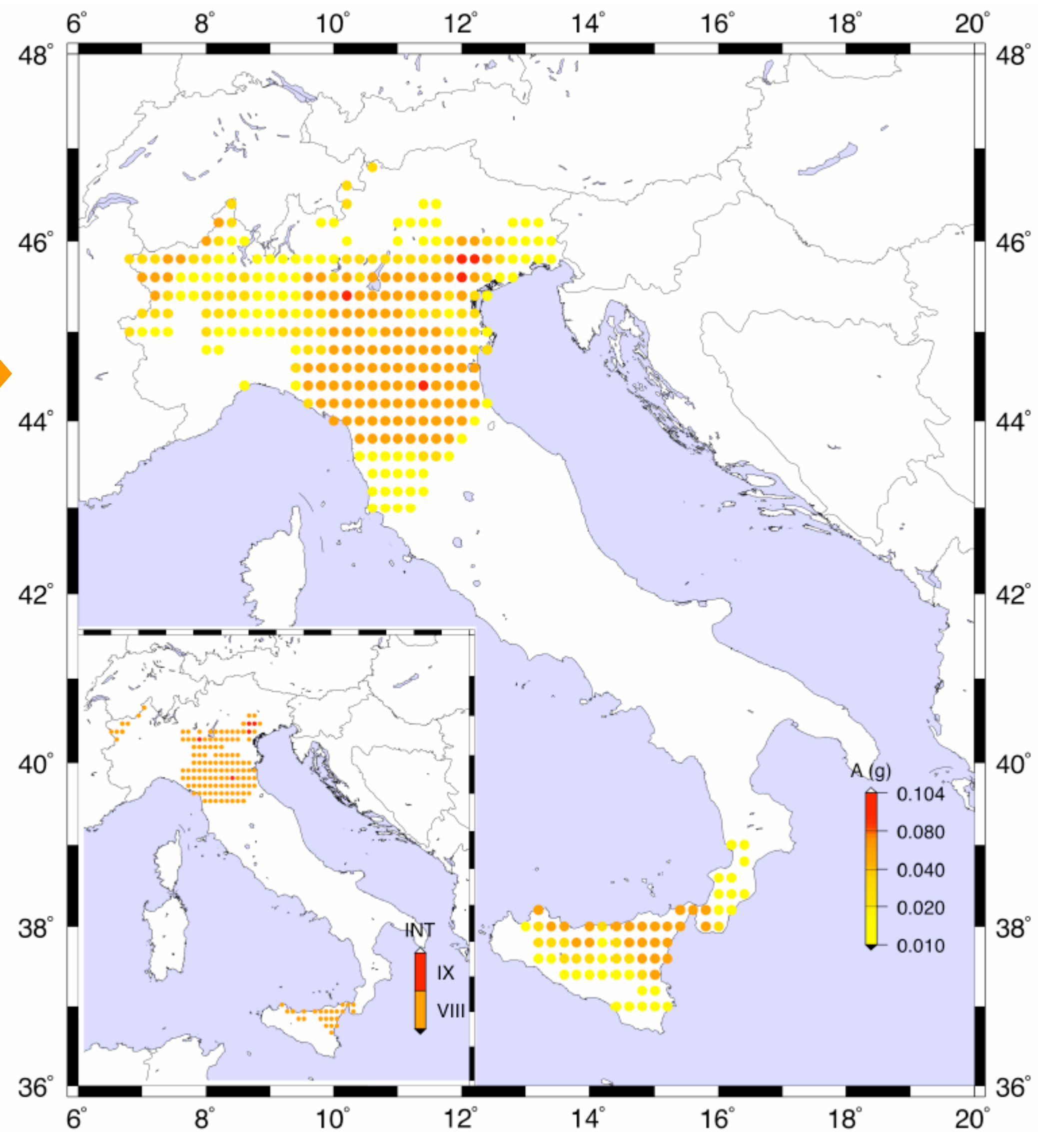
Neo-deterministic Method

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

Prediction of earthquakes with M5.5+



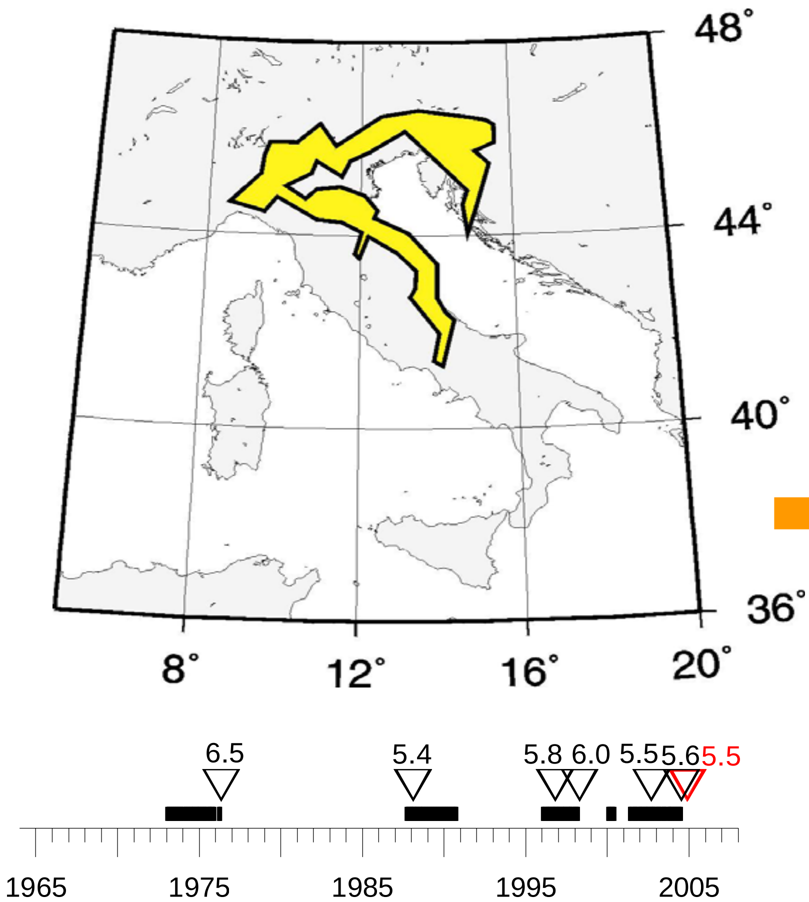
Alerted areas by M8S algorithm
for an earthquake with 5.5≤M<6.0
(as on 1 July 2006 – 1 January 2007)

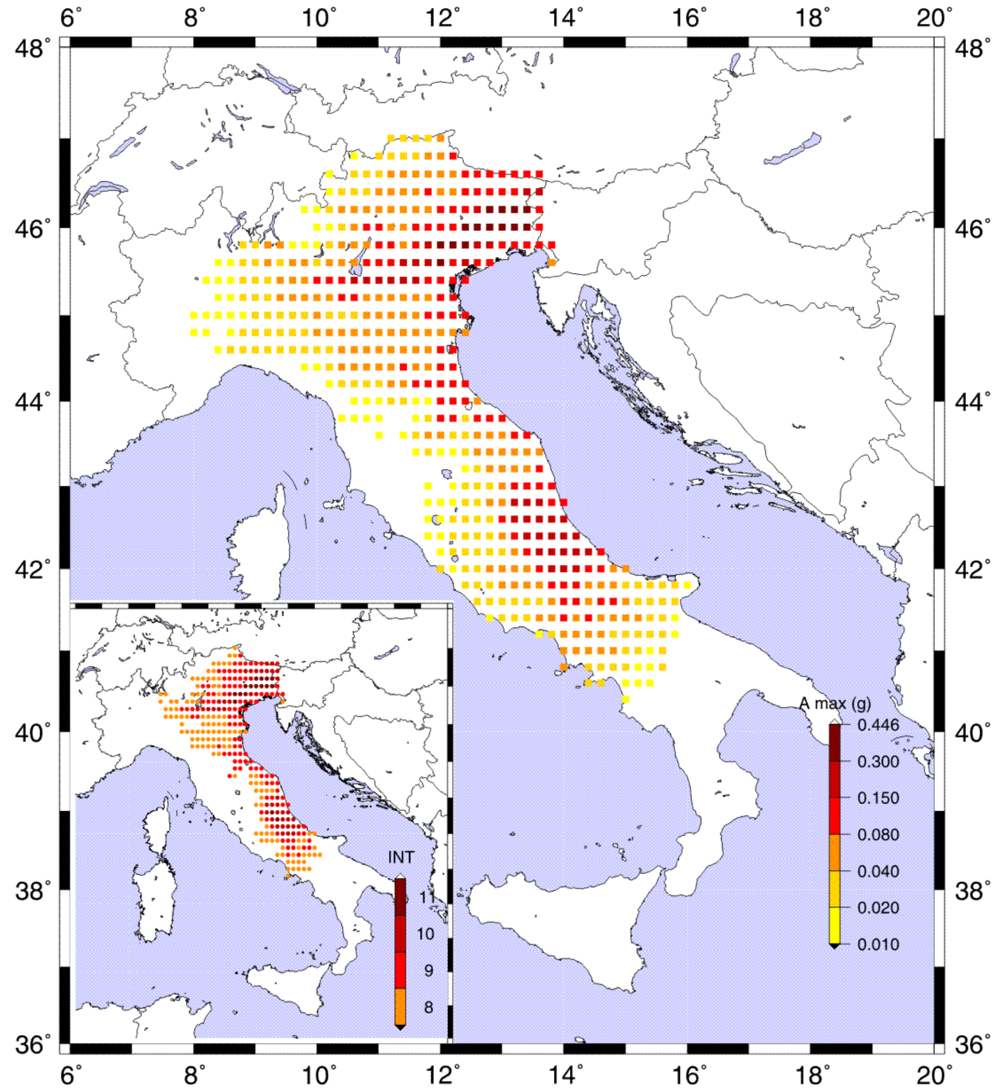


Neo-deterministic hazard scenarios associated to alerted regions: CN algorithm

Northern Region

Prediction of earthquakes with M≥5.4

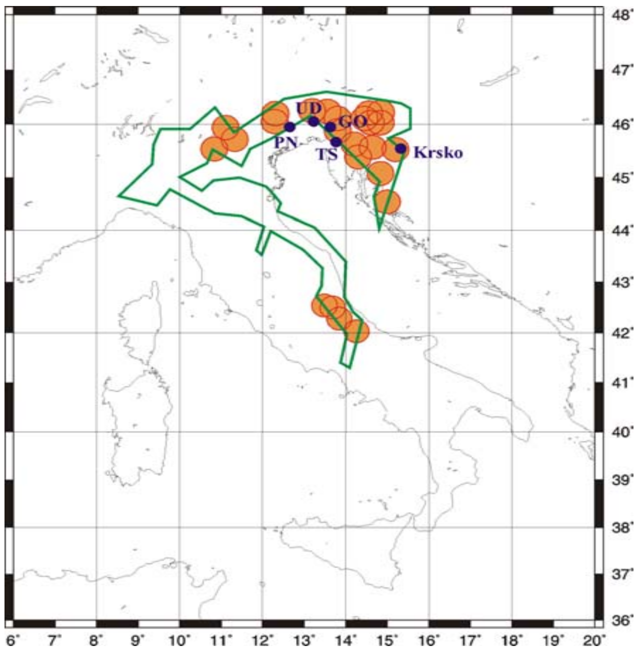




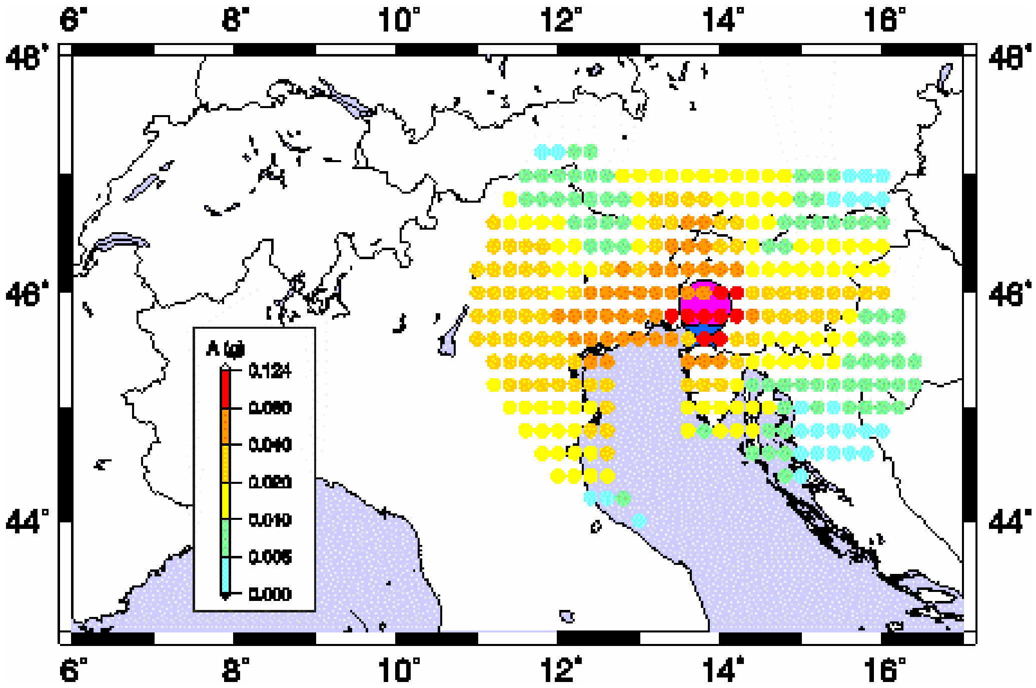
Scenario associated to earthquake prone nodes

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

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



M≥6.5



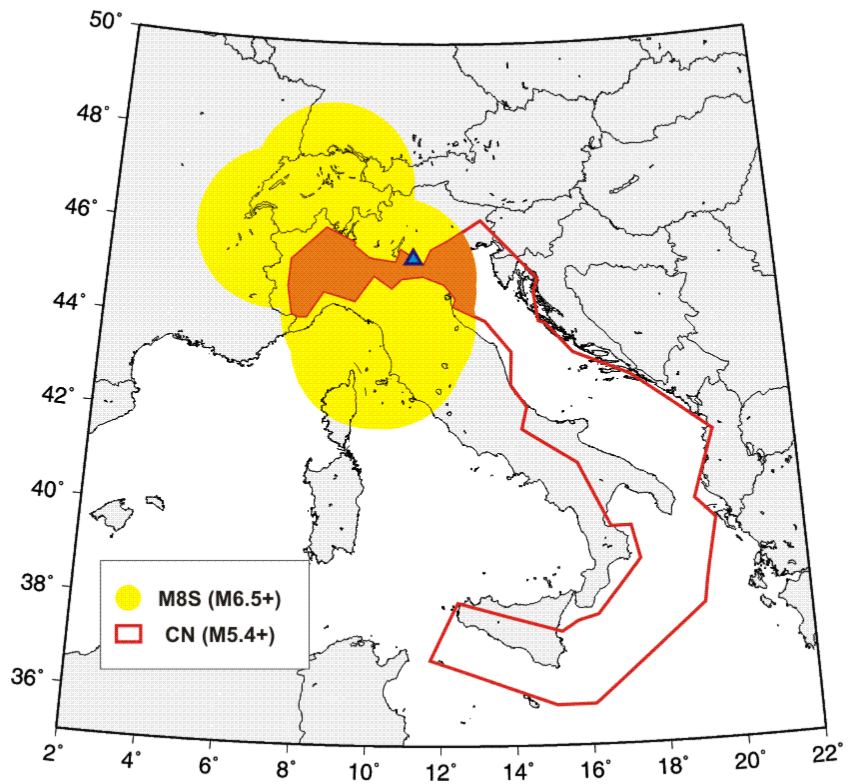
PGD (cm)	PGV (cm/s)	DGA (g)	I_{max} computed ING	I_{max} computed ISG	I_{max} observed
2.0 – 3.5	4.0 – 8.0	0.08-0.15	IX	VIII	VII

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

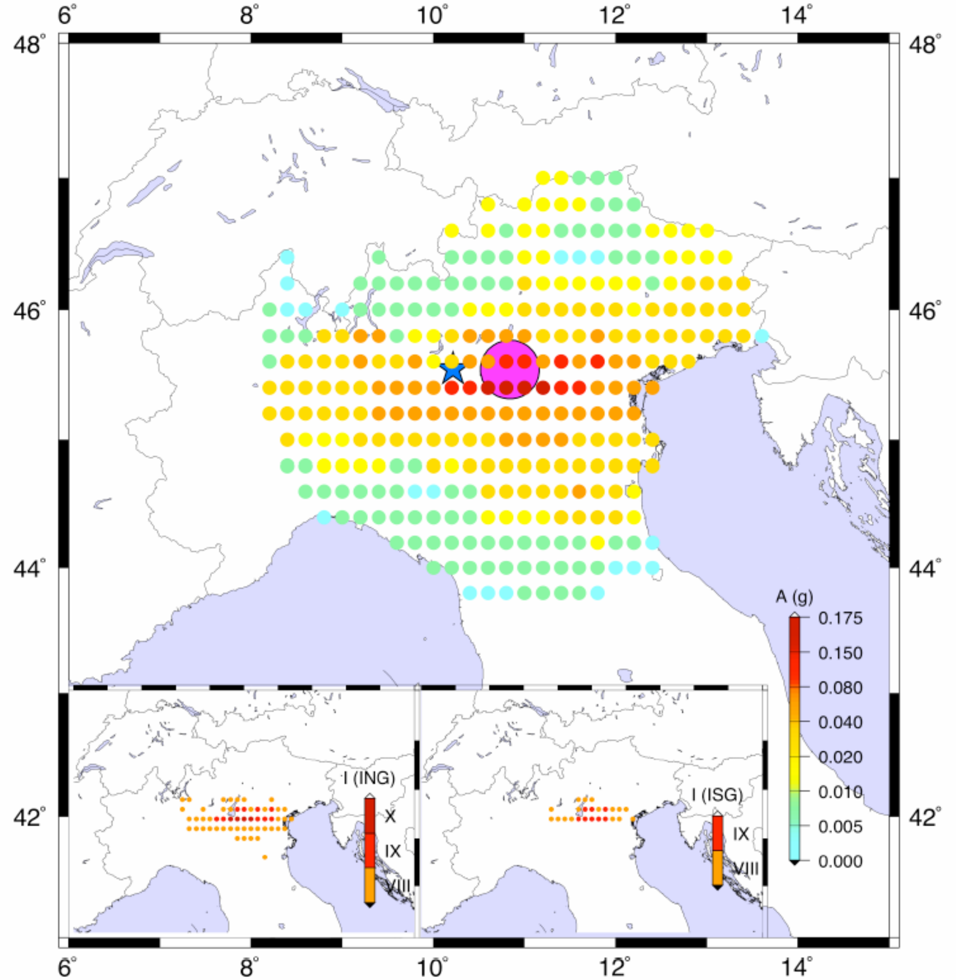
Scenario associated to earthquake prone nodes

Example: earthquake with M=6.5 occurring at the node within the alerted region

(compatible with seismic history and seismotectonics)



Situation of alarms as on July-December 2006



Design Ground Acceleration (DGA) and maximum computed intensity (I_{max} computed), estimated using the conversion tables proposed by Panza et al. (2001) based on ING and ISG data sets.

Multiscale Neo-deterministic Hazard Scenarios

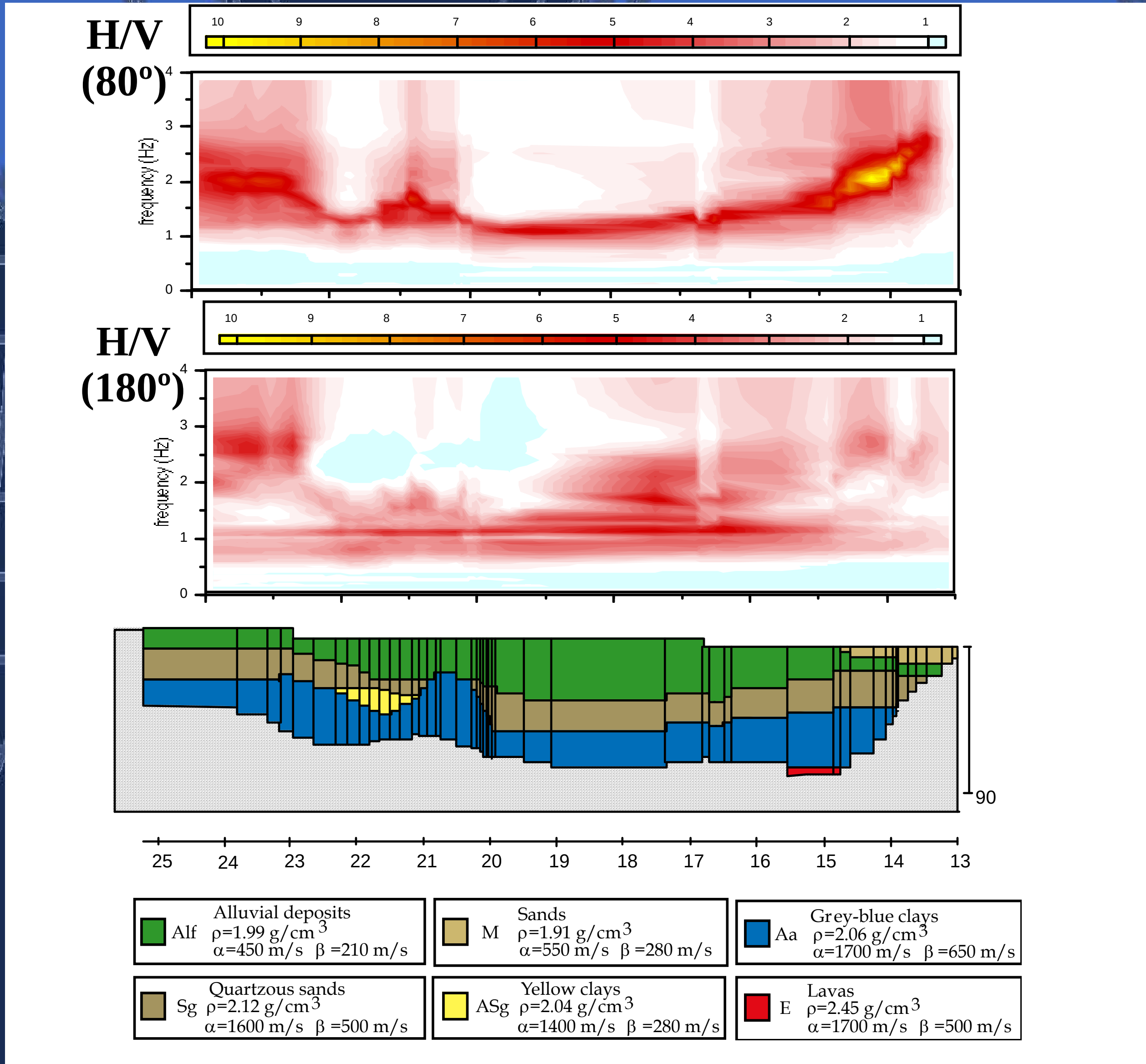
Seismic Microzoning

(including lateral heterogeneities)

The use of synthetic computations is necessary to overcome the fact that the so-called local site effects can be strongly dependent upon the properties of the seismic source generating the seismic input (Panza et al, 2000).

- **H/V:** is the spectral ratio between the horizontal and vertical components of motion.
- **RSR:** is the ratio between the amplitudes of the response spectra, for 5% damping, obtained considering the bedrock structure, and the corresponding values, computed taking into account the local heterogeneous medium.

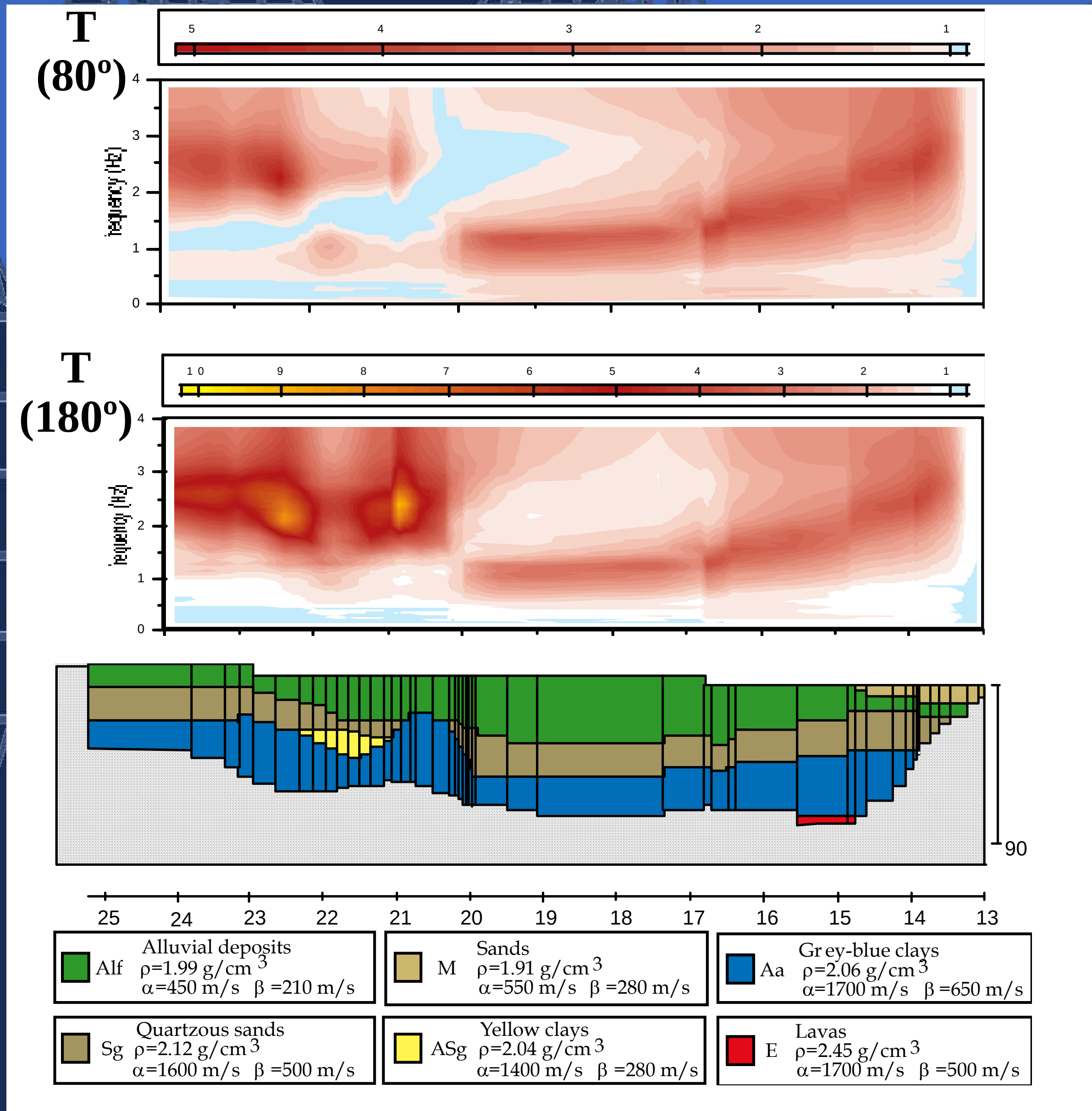
Modeling of seismic input
(azimuth effect)



H/V spectral ratio

Modeling of seismic input

(azimuth effect)



RSR for the SH component of motion

About convolutive/deconvolutive methods

In the far field (and in the point source approximation, i.e. in the simplest possible case) the displacement (the seismogram) is:

$u_k(t)=M_{ij}(t)*G_{ki,j}(t)$

k, i and j are indices and ,j means derivative, * means convolution, G is the Green's function and M_{ij} are moment tensor rate functions.

If the M_{ij} are considered to be independent in the description of the source, the above equation is linear (it corresponds to a mechanism generally varying with time).

About convolutive/deconvolutive methods

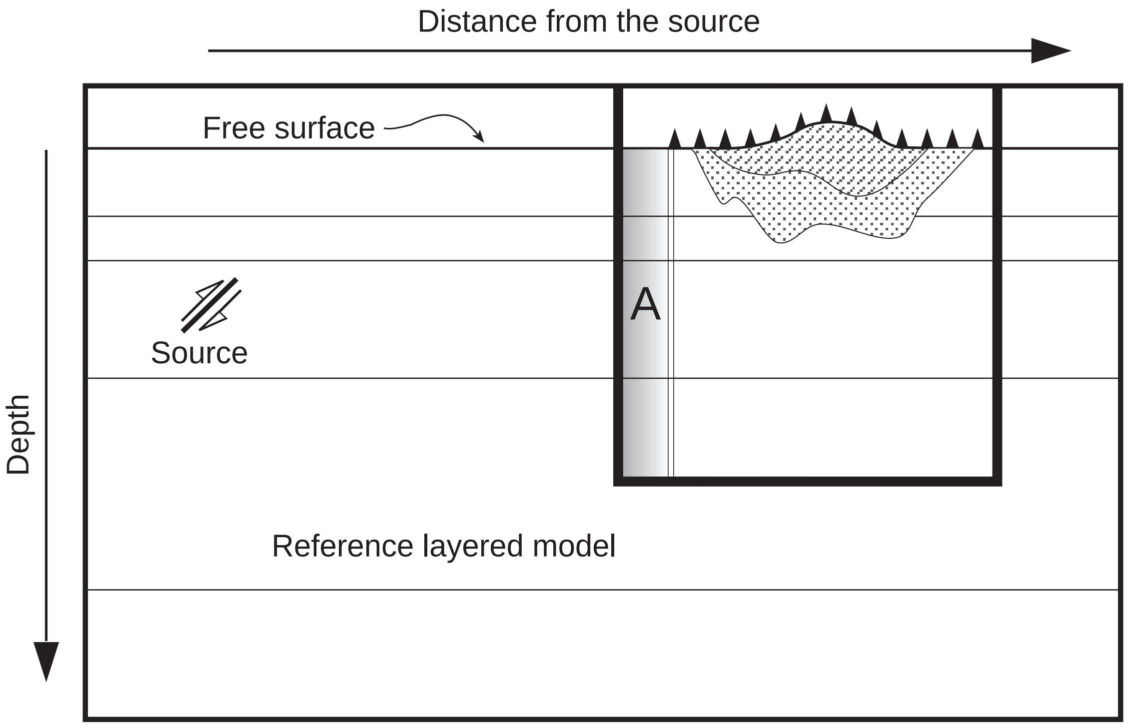
However, if we constrain the independence of M_{ij} and ask for a constant mechanism (even unconstrained one, i.e. the full moment tensor), i.e. if we impose the constraint $M_{ij}(t)=M_{ij}.m(t)$ the problem becomes non-linear because of the product on the right-hand side of:

$$u_k(t)=M_{ij}.m(t)*G_{ki,j}(t)$$

both M_{ij} and $m(t)$ are model parameters controlling source properties.

Thus, the problem in the time domain is non-linear even without the DC constraint (the DC constraint is an additional non-linearity here).

Hybrid Method:
Modal Summation + Finite Differences



Artificial boundaries, limiting the FD grid.

A Zone of high attenuation, where Q is decreasing linearly toward the artificial boundary.

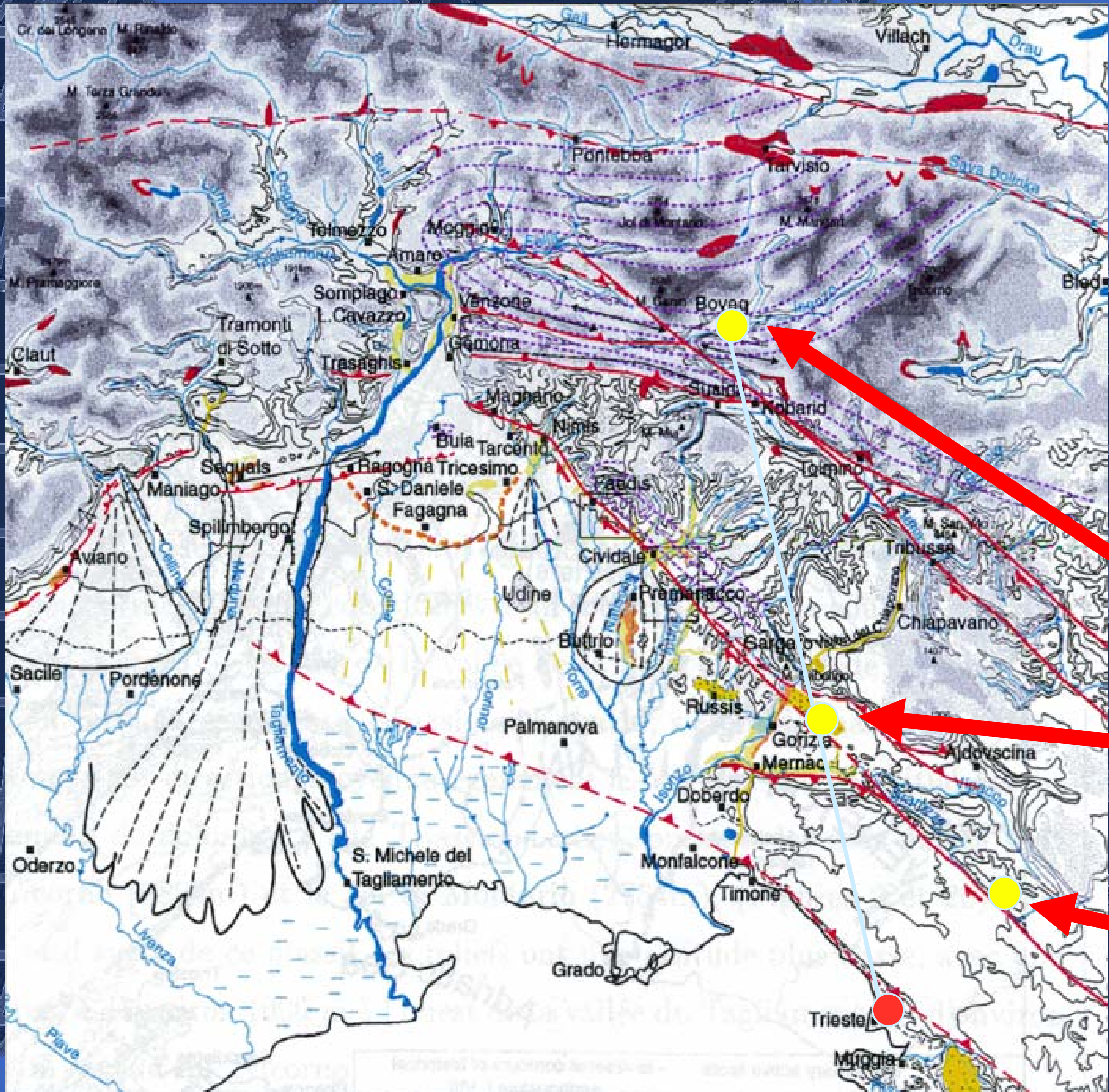
Local heterogeneous model

Adjacent grid lines, where the wave field is introduced into the FD grid. The incoming wave field is computed with the mode summation technique. The two grid lines are transparent for backscattered waves (Alterman and Karal, 1968).

▲ Site

Detailed scenario of ground motion including local site effects

Example: scenarios of ground motion in the city of Trieste

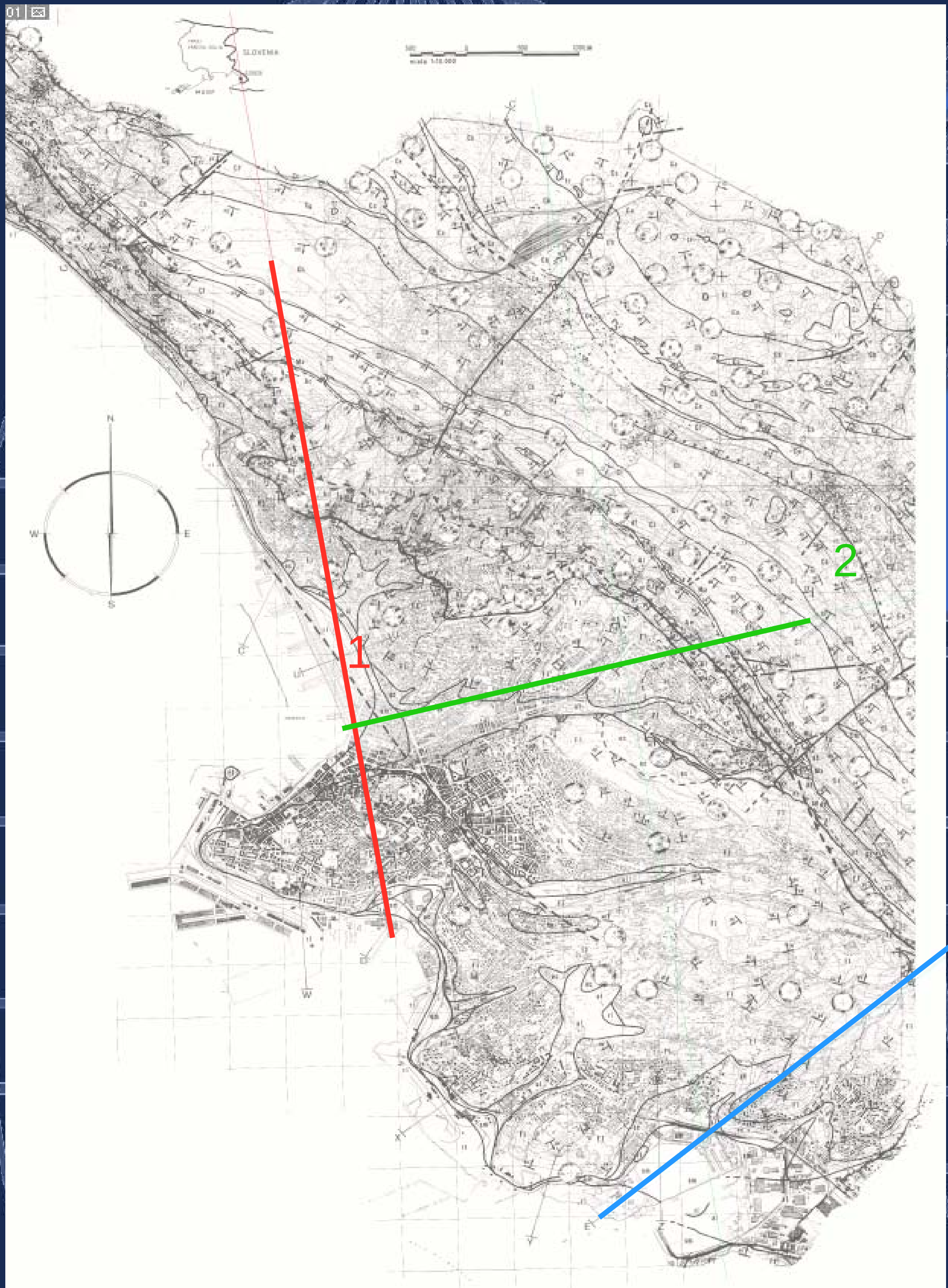


Based on the morphostructural zonation and on the identified **earthquake prone areas**, three possible seismic sources have been considered for ground motion modelling in Trieste:

A seismic source in the Bovec zone (65 km from Trieste)

A seismic source East of Gorizia (30 km from Trieste)

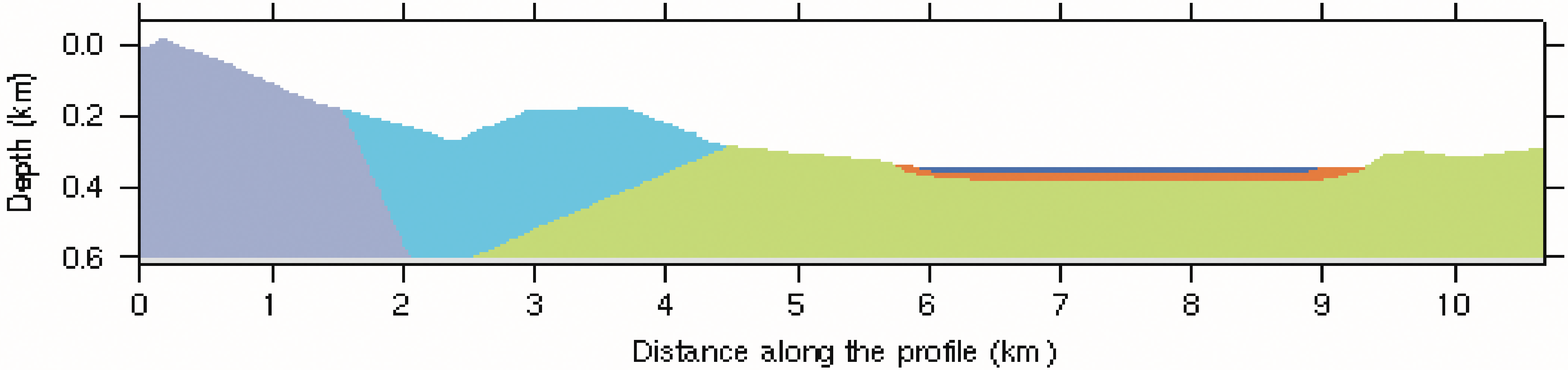
The closest seismic source at 17 km from Trieste



The modeling of ground motion and the evaluation of expected amplifications are performed considering the following profiles:

- Roiano - Palazzo Carciotti (1)
- DST - Palazzo Carciotti (2)
- Zona Industriale (E)

Definition of the local model



	Descr.	Rho	Vp	Qp	Vs	Qs
	Aria	0.000	0.000	0	0.000	0
	Riporti	1.800	0.420	30	0.200	15
	Sed. marini	1.900	0.800	40	0.400	20
	Flysch	2.000	1.800	100	1.000	50
	Arenarie	2.100	2.000	200	1.200	100
	Calcari	2.300	2.500	200	1.400	100

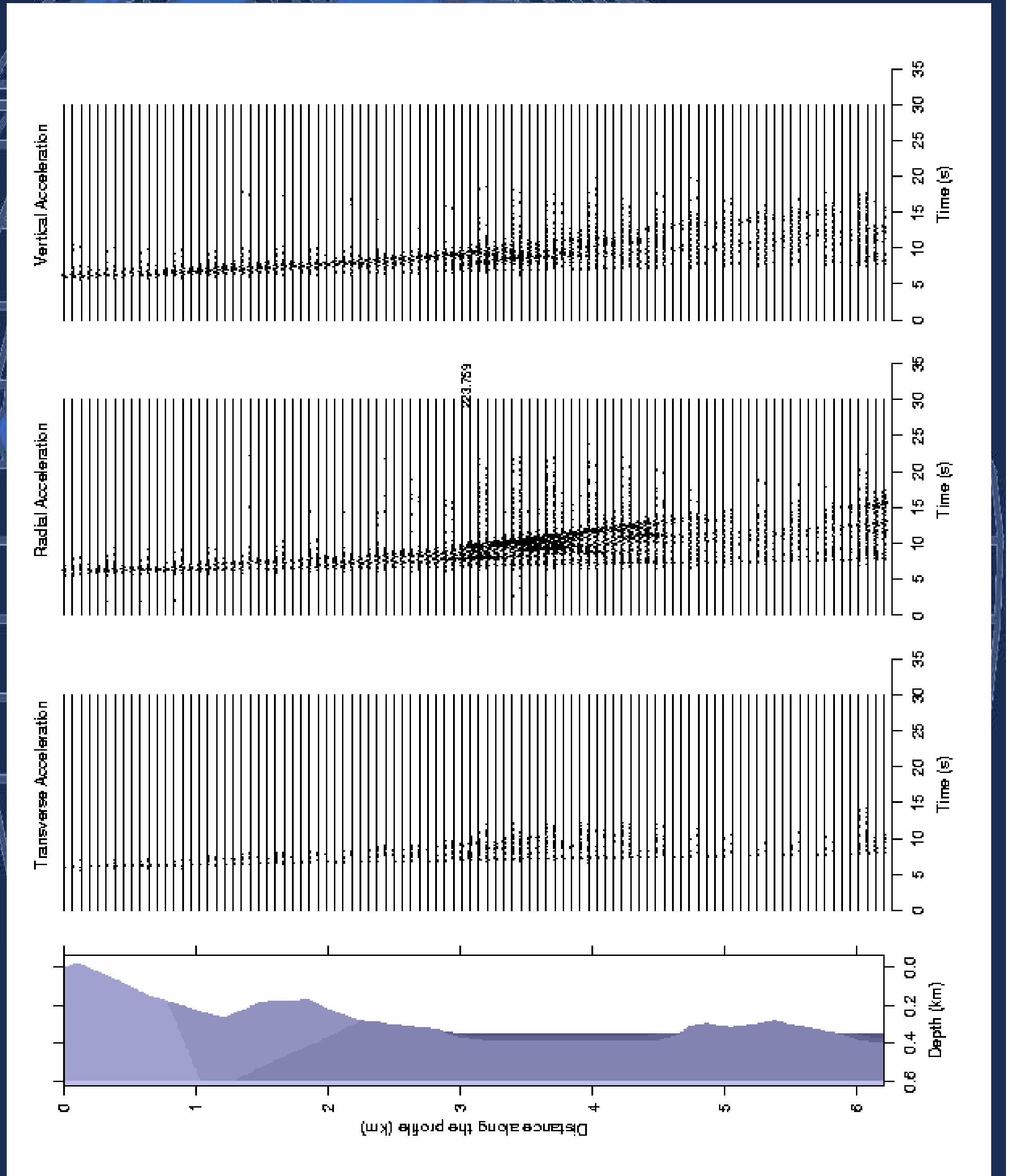
Synthetic Seismograms

Transverse component of ground motion: displacement, velocity and acceleration

(Radial and vertical components can be considered as well).

- **Effect of the low-velocity basin: amplification of the ground motion and longer duration of the shaking.**
- **The synthetic seismograms constitute the seismic input for the modeling of the response of the buildings.**

Profile 1 - Bedrock “B” - Dist. 17 km - M=6.0
Synthetic Seismograms



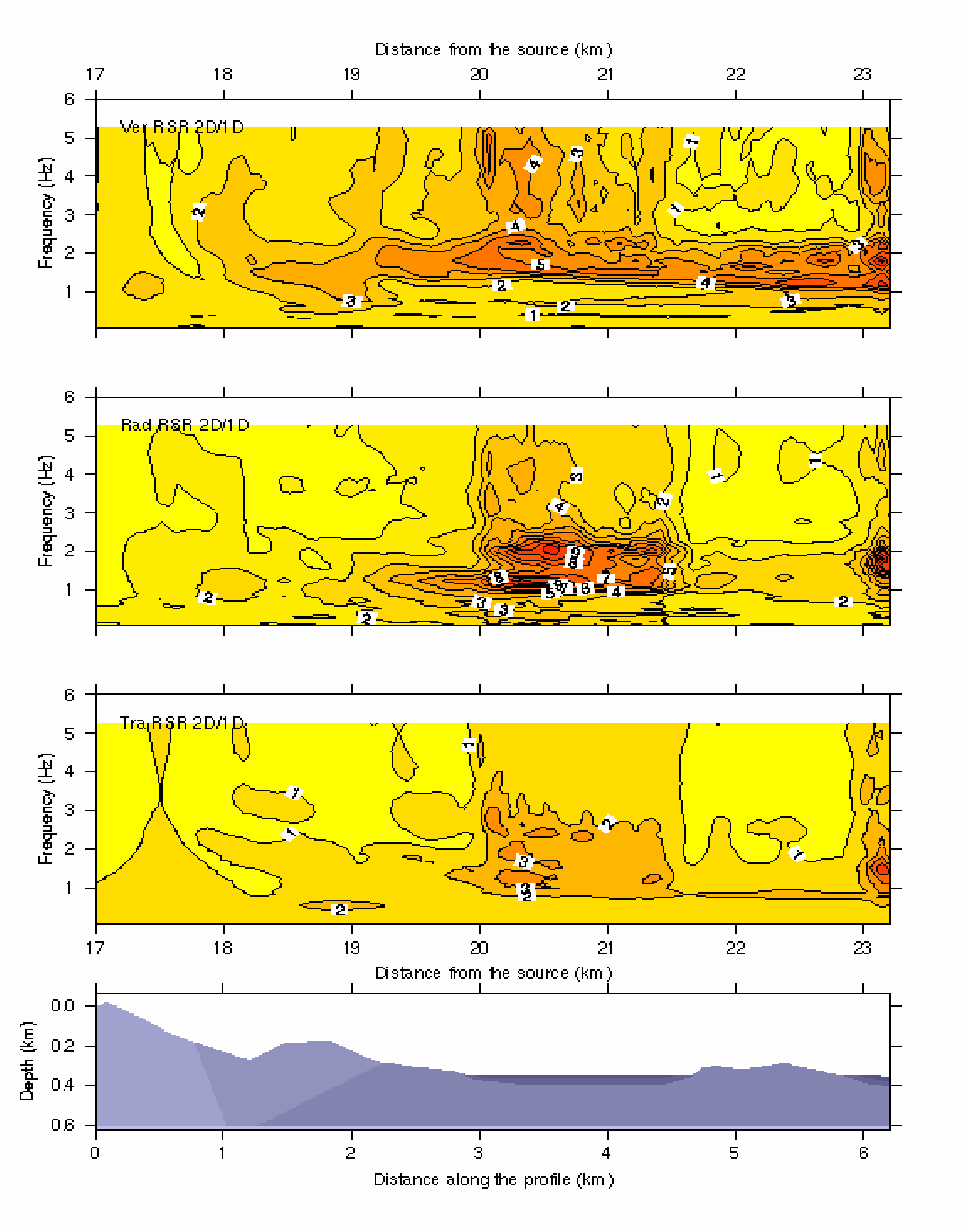
Response Spectra Ratio

Estimate of the amplification of the ground motion along the profile (RSR 2D/1D)

It is obtained computing at each site and for each component the ratio between the response spectrum of the signal and the response spectrum of a signal computed at the same location using a reference bedrock model.

Site effects in Trieste city centre may cause a significant amplification (up to 5 times at engineering relevant frequencies) of the seismic signal at bedrock, hence intensity may reach IX (MCS) or VIII (MSK).

Profile 1 - Bedrock "B" - Dist. 17 km - M=6.0
Accelerations and Amplifications



Engineering analysis

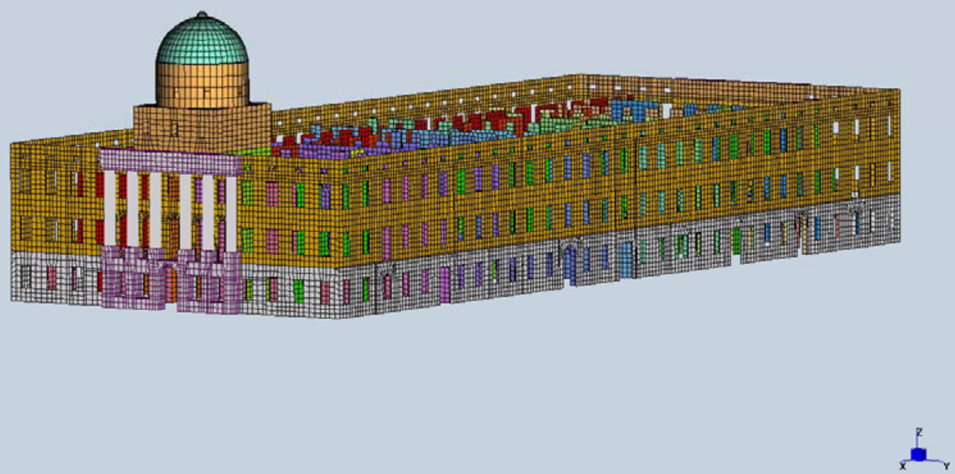
The data set of synthetic seismograms can be fruitfully used and analysed by civil engineers for design and reinforcement actions, and therefore supply a particularly powerful and economical tool for the prevention aspects of Civil Defence.

Non-linear dynamic analysis considering the seismic input provided by the complete synthetic accelerograms as obtained from microzoning $\Rightarrow$ Evaluate the response of relevant man-made structures, in terms of displacements and stresses, with respect to a set of possible scenario earthquakes

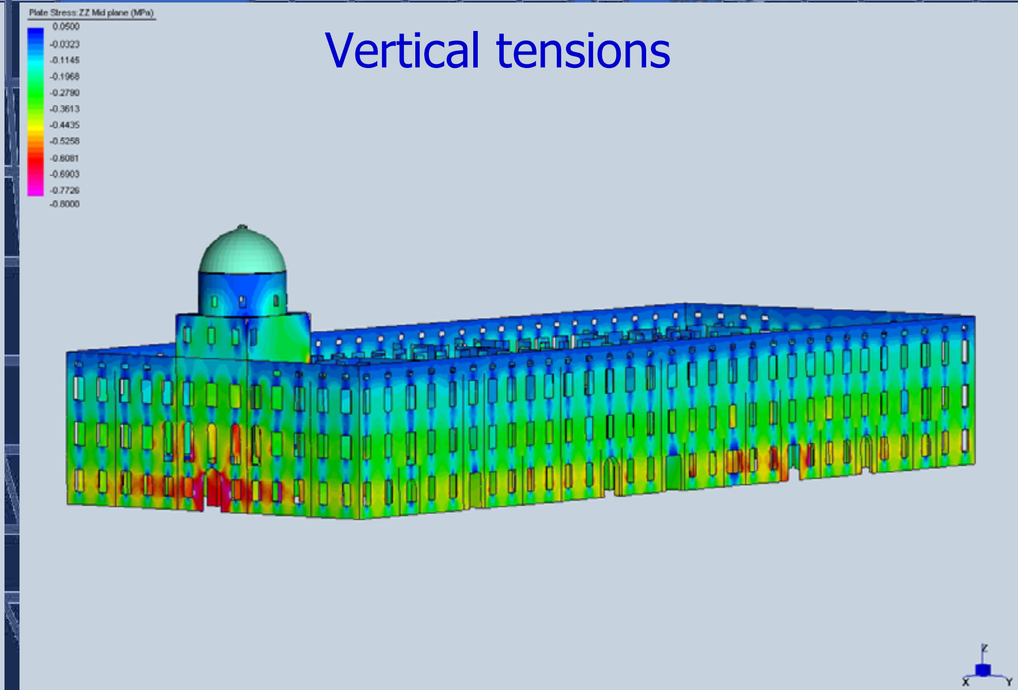
Engineering analysis

PALAZZO CARCIOTTI
(masonry)

Model



Vertical tensions



Seismic base isolation

Among the cost effective advance action aimed at creating knowledge based hazard resilient public assets a particular role is played by seismic isolation.

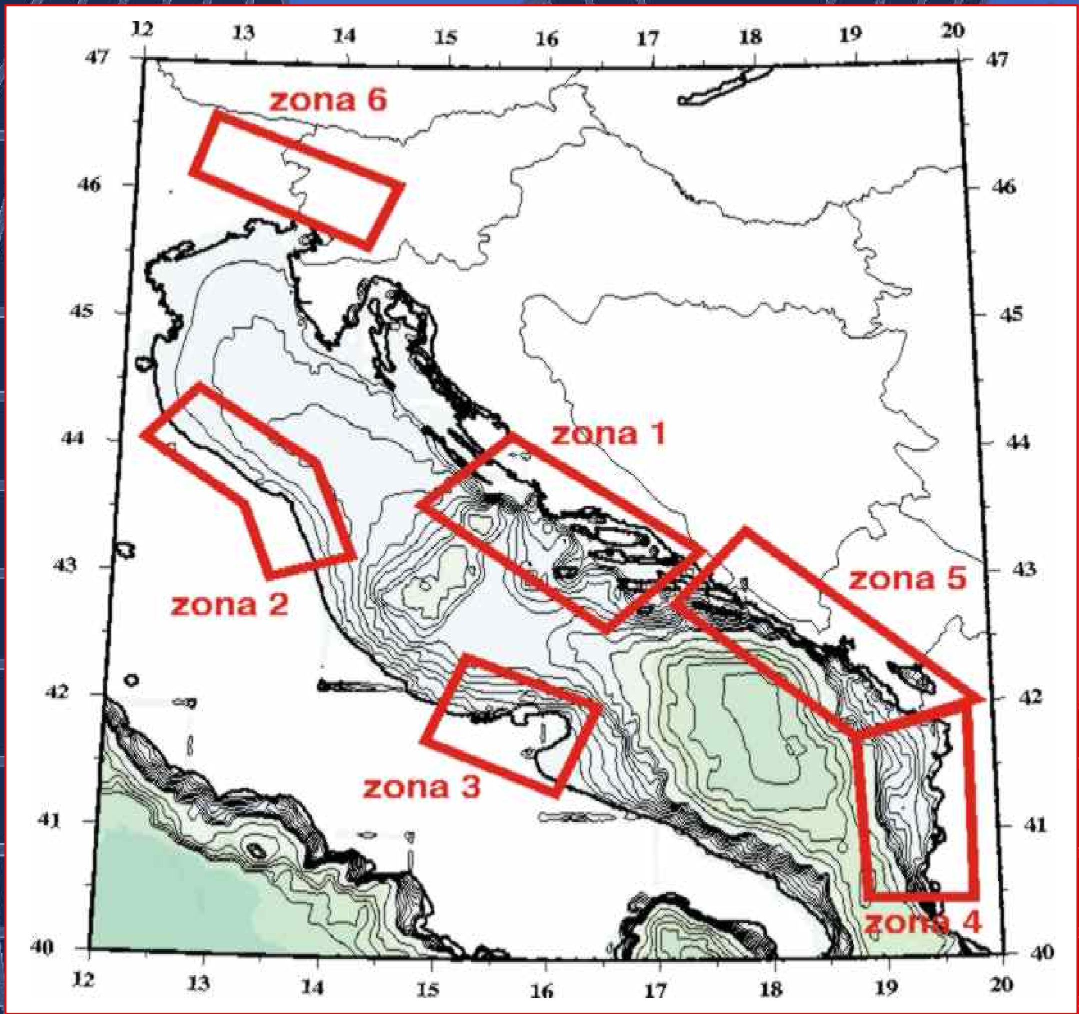
The seismic isolation systems (rubber bearings, frictional type systems, etc.) need to have sufficient displacement and energy dissipation capacities.

Dinamical test of a seismically isolated building at Rapolla (*Braga and Laterza, 2000*)

Multiscale Neo-deterministic Hazard Scenarios

Tsunami scenarios

Principal tsunamigenic areas for the Northern Adriatic basin



Zone 1: Central Adriatic and Croatia coast

Zone 2: Italian eastern coast

Zone 3: Gargano

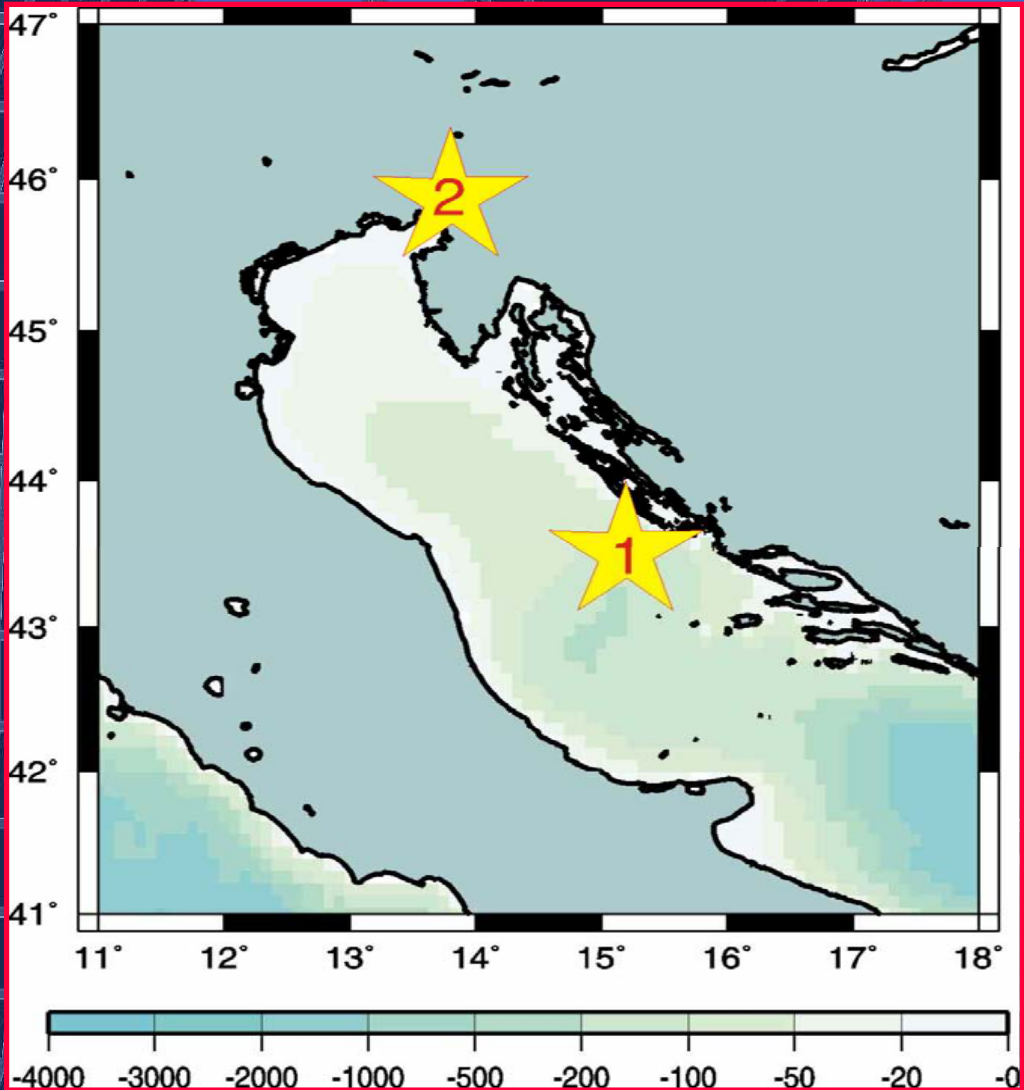
Zone 4: Northern Albania coast

Zone 5: Southern Croatia, Bosnia-Herzegovina and Northern Albania

Zone 6: Julia and Friuli

Adriatic basin

Principal tsunamigenic areas for the Northern Adriatic basin



Two possible source localizations adopted for the tsunami modeling and the realization of tsunami hazard scenarios:

1) **offshore**, in front of the Croatian coastlines, where many historical tsunamis occurred

2) **inland**, associated to the historical event of 26/3/1511

Adriatic basin

Source 2 scenario

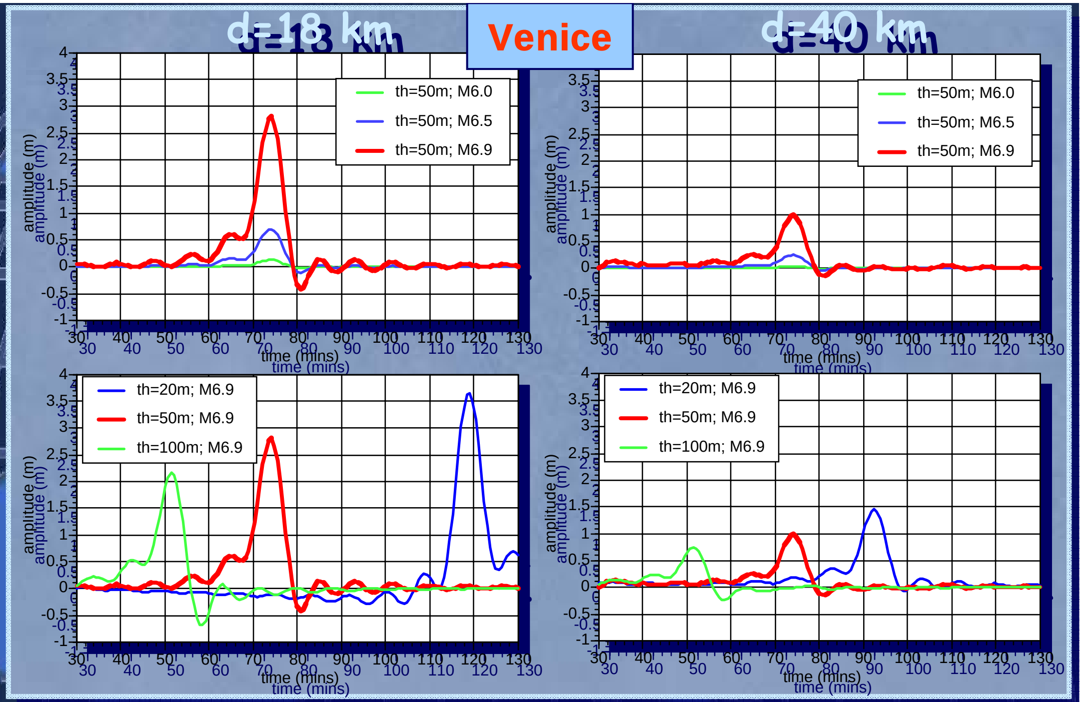
The tsunamis are computed for different scenarios, compatible with seismic history and seismotectonics:

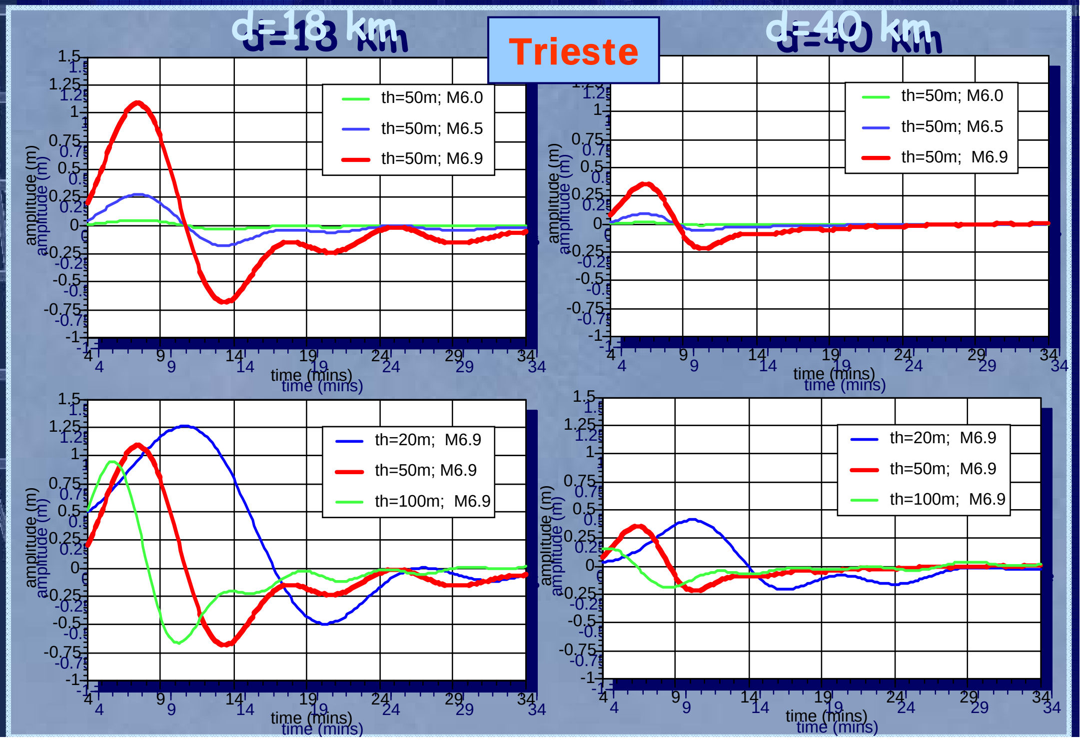
a) M=6.0, M=6.5 and M=6.9

b) different thicknesses of the liquid layer: 20, 50 and 100m.

c) 2 distances of the source from the coastline: 18 and 40 km.

Inland source ® Green-function approach





Historical tsunami in the Northern Adriatic basin

Among the 26 historical tsunamis reported for the Adriatic basin, there are the following:

- *Gulf of Venice, 1348:* "...per la forte commozione del suolo restò asciutto il fondo del Canal Grande”
- *Gulfs of Venice and Trieste, 1511:* 'le ondate costrinsero la popolazione di Trieste a mettersi in salvo nella parte alta della città...a Venezia le onde si elevarono fino all’altezza delle finestre delle case”

The ASI-SISMA project:
integrating data from earth-observations

ASI Pilot Project - SISMA
“Seismic Information System for Monitoring and Alert”

Development of a system, based on the neo-deterministic approach for the estimation of seismic ground motion, integrating the space and time dependent information provided by **real-time monitoring of seismic flow** and **EO data** analysis, through **geophysical forward modeling.**

agenzia spaziale italiana

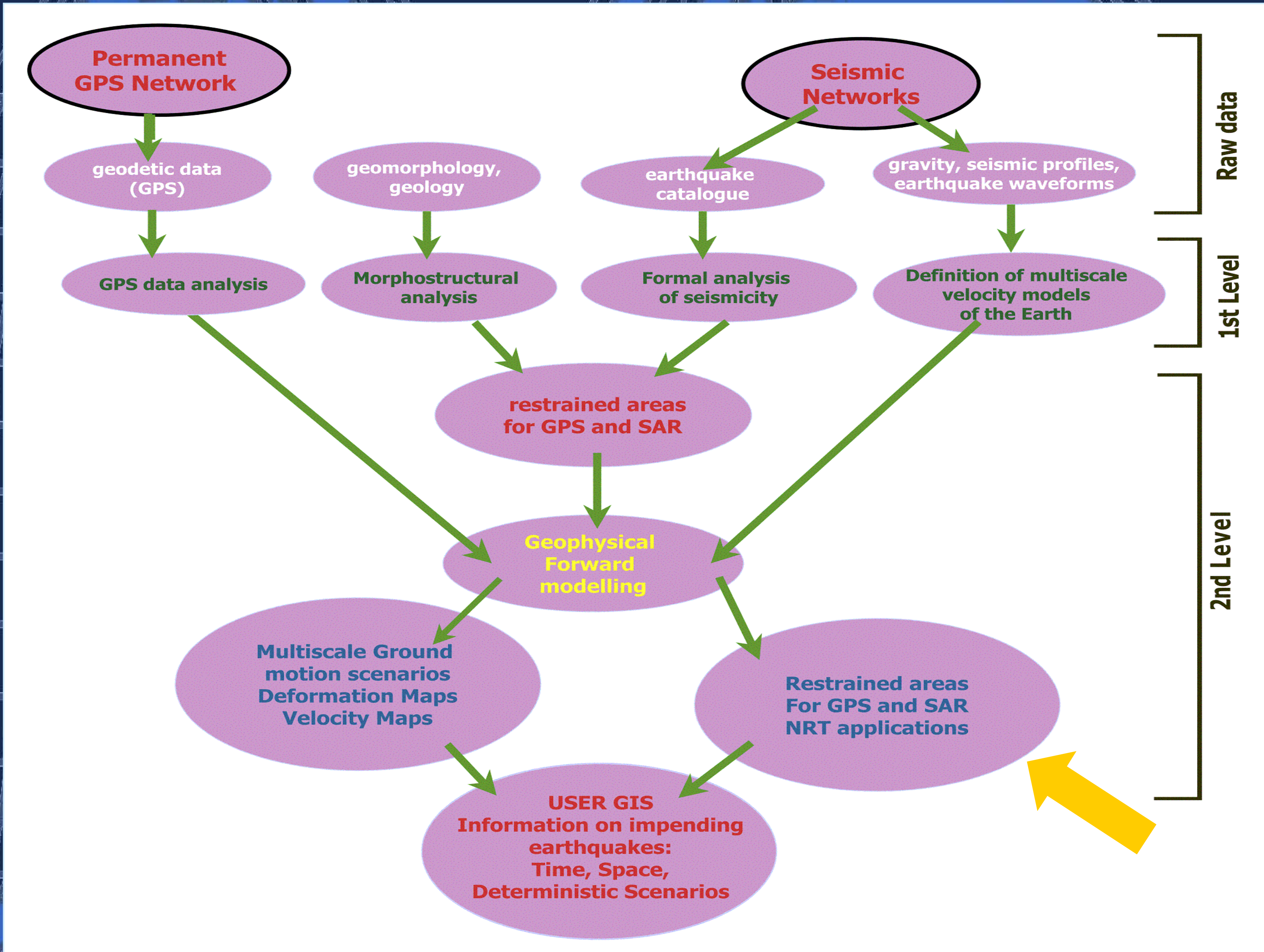
DST

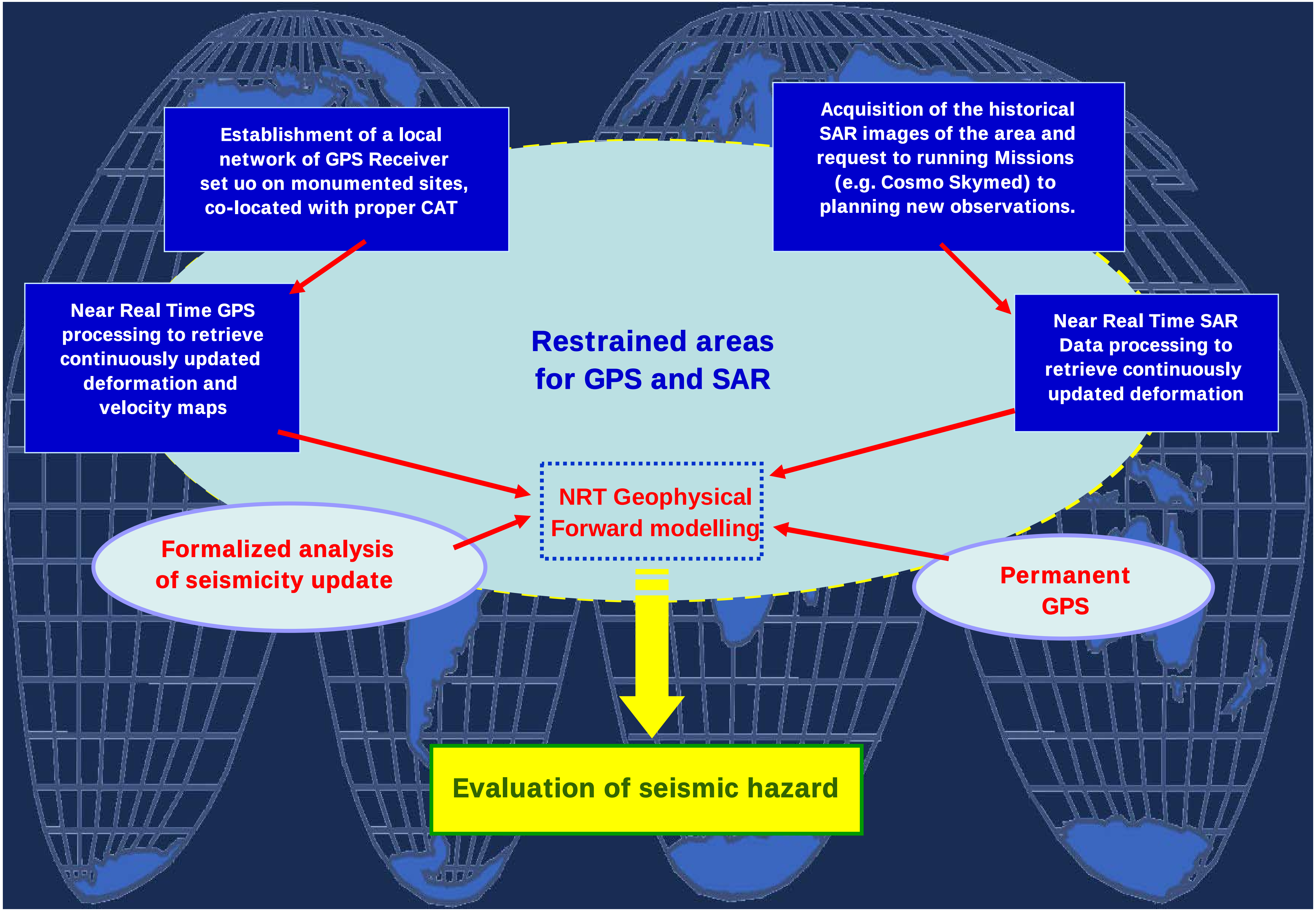
University of Milano

Politecnico di Milano

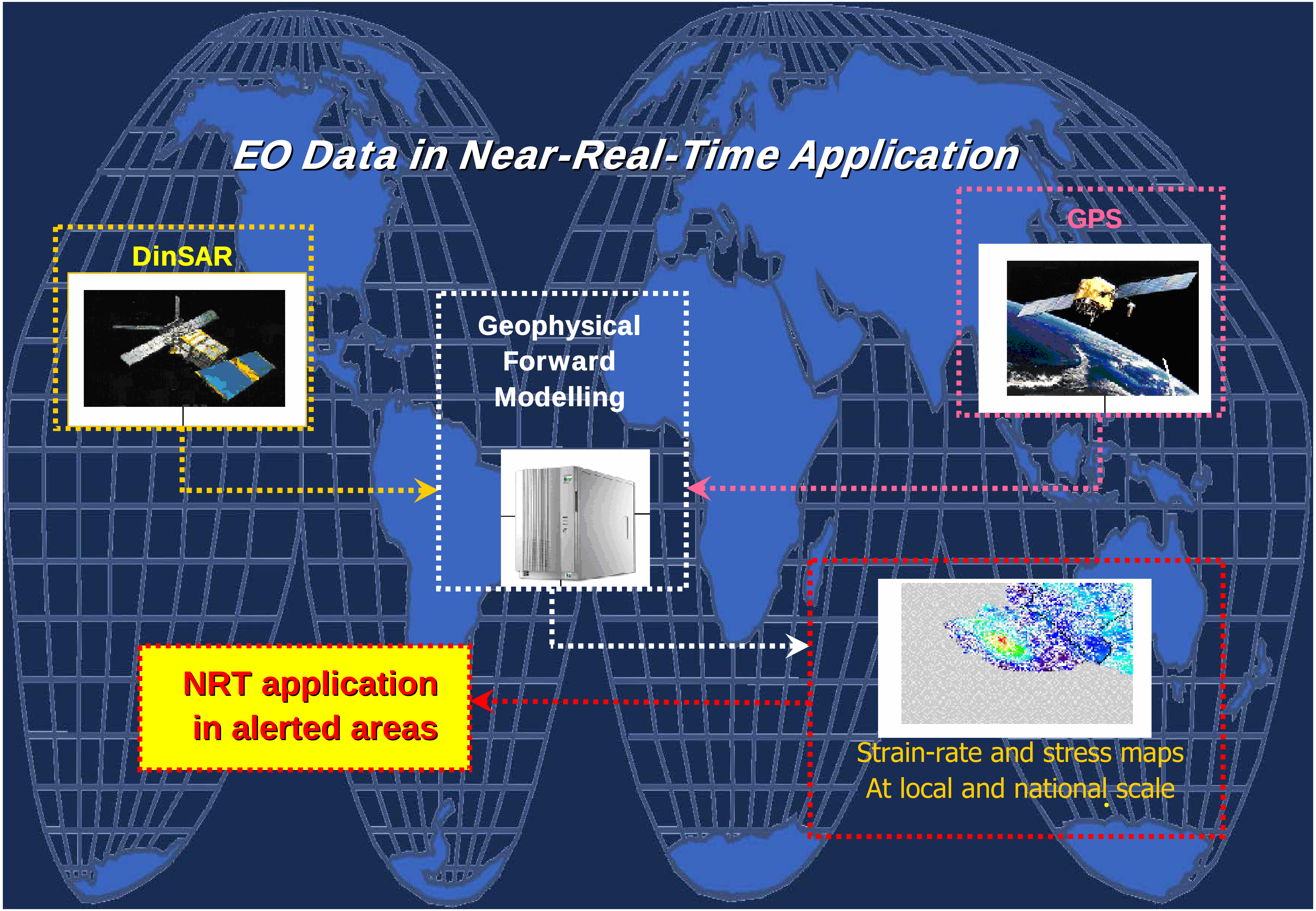
galileian PLUS

SISMA Overall Description



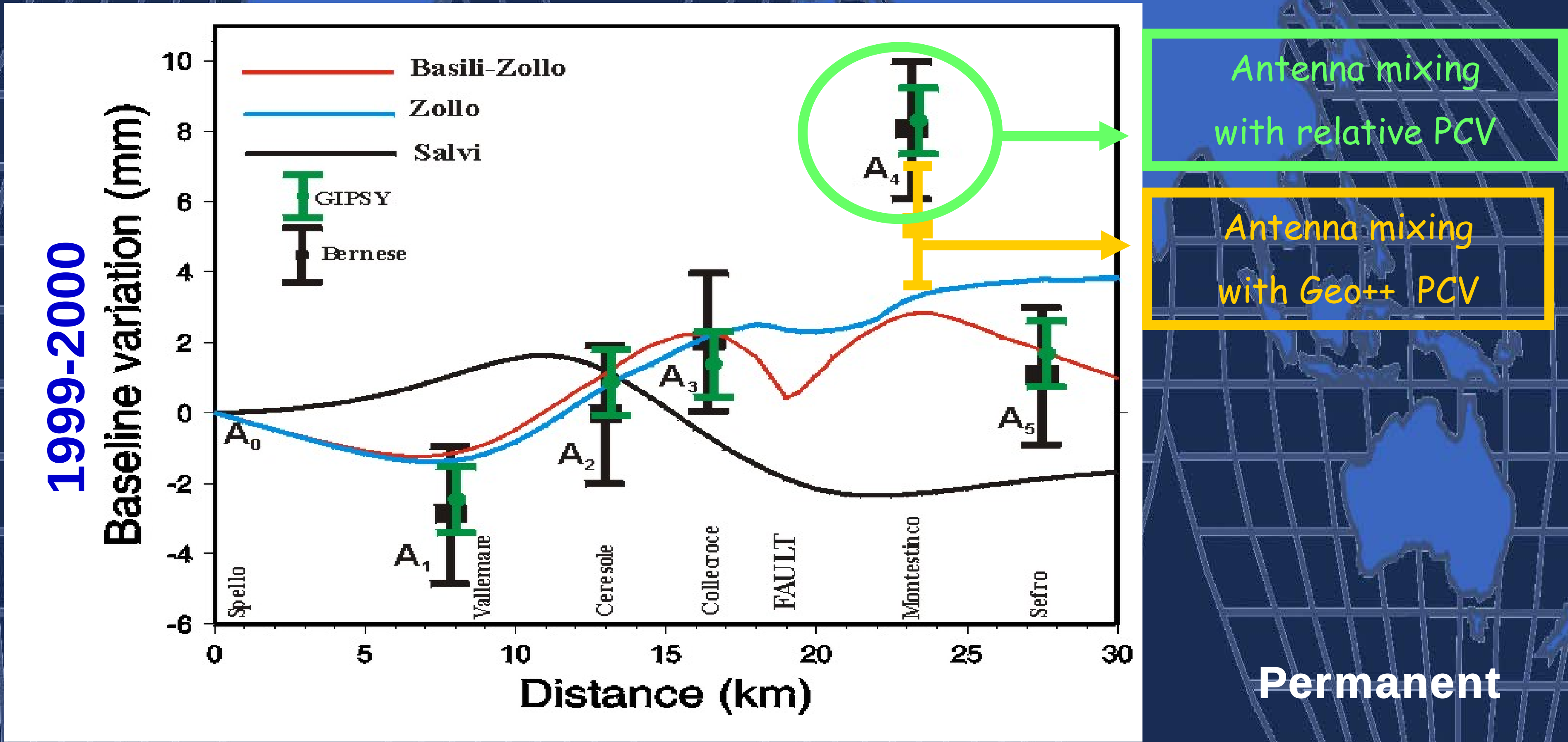

Establishment of a local network of GPS Receiver set uo on monumented sites, co-located with proper CAT
Acquisition of the historical SAR images of the area and request to running Missions (e.g. Cosmo Skymed) to planning new observations.
Near Real Time GPS processing to retrieve continuously updated deformation and velocity maps
Restrained areas for GPS and SAR
Near Real Time SAR Data processing to retrieve continuously updated deformation
NRT Geophysical Forward modelling
Formalized analysis of seismicity update
Permanent GPS
Evaluation of seismic hazard

- 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.



EO Data in Near-Real-Time Application
DinSAR
GPS
Geophysical Forward Modelling
NRT application in alerted areas
Strain-rate and stress maps
At local and national scale

The Umbria-Marche baseline variations

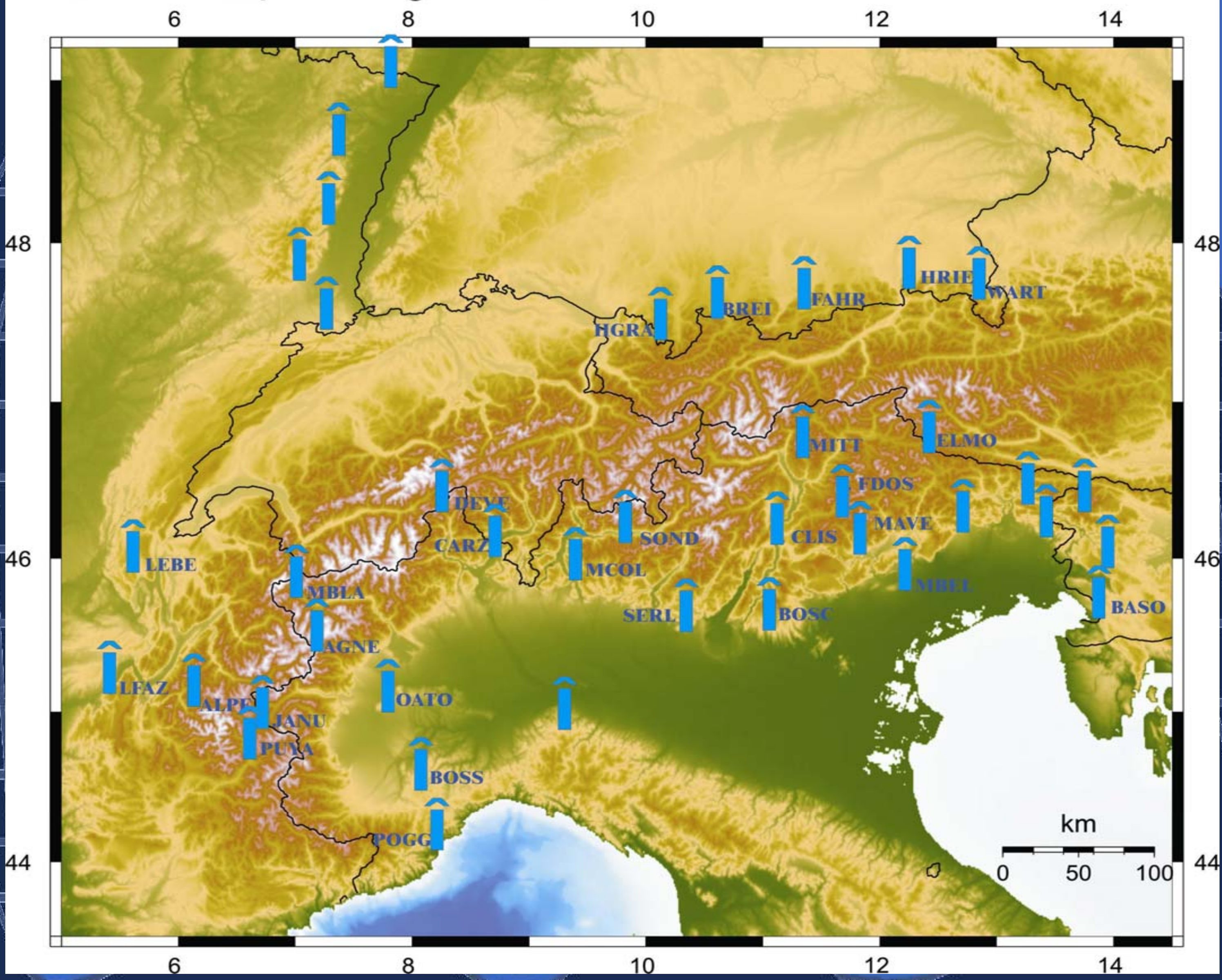


Permanent GPS data

ALPS GPSQUAKENET

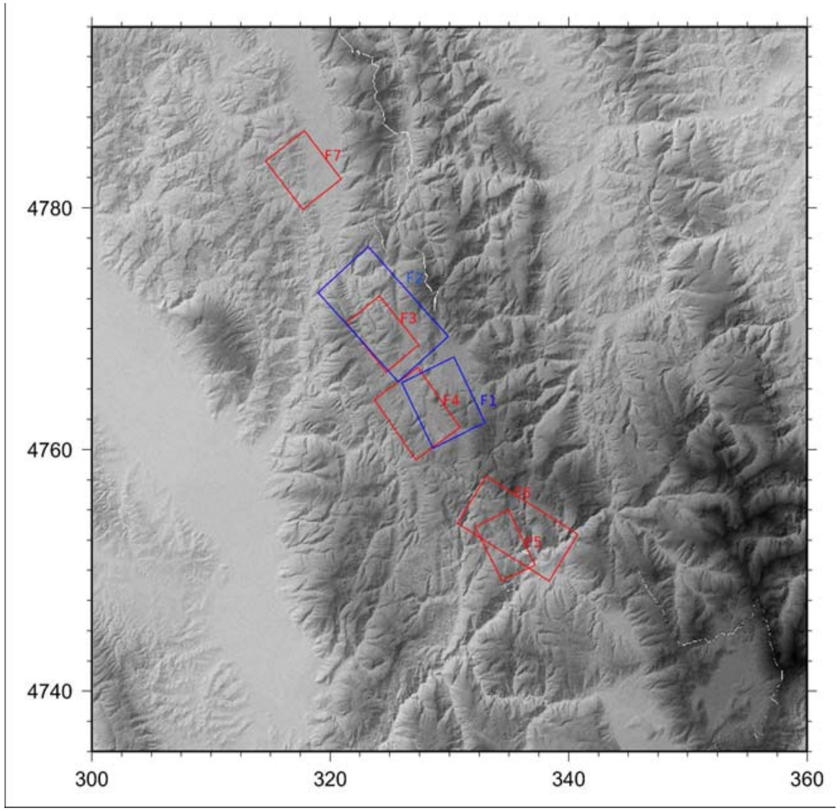
Interreg III B

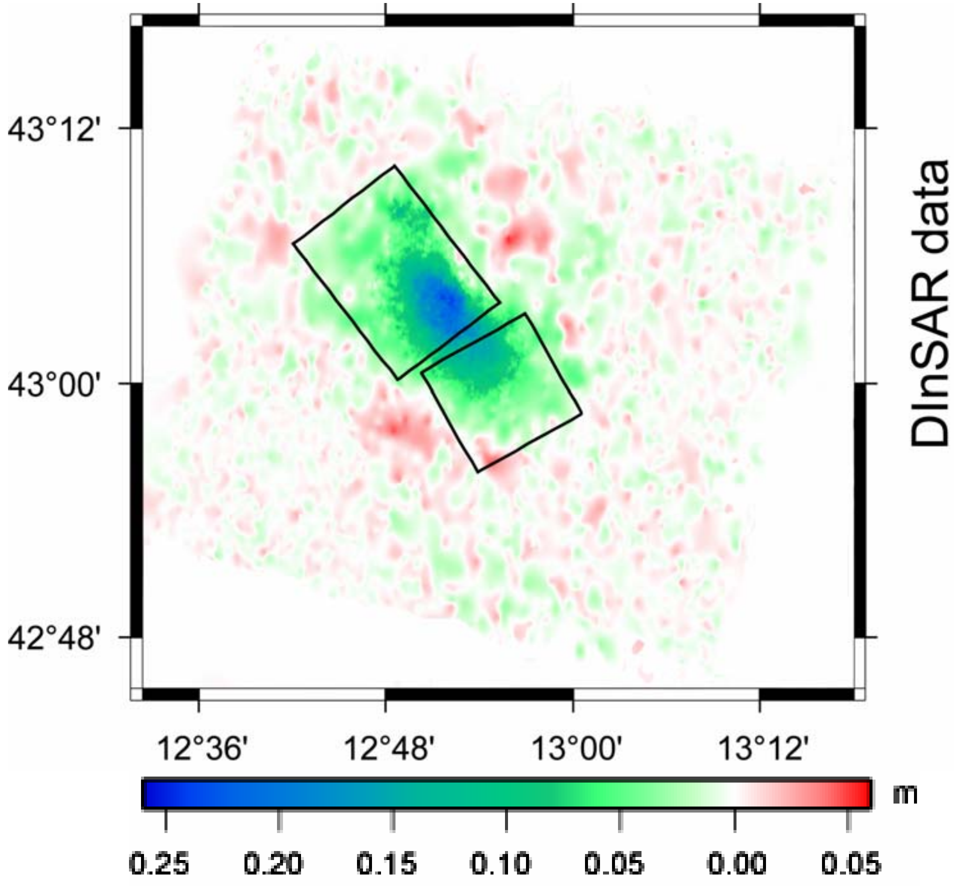
GAIN -
Geodetic Alpine Integrated Network



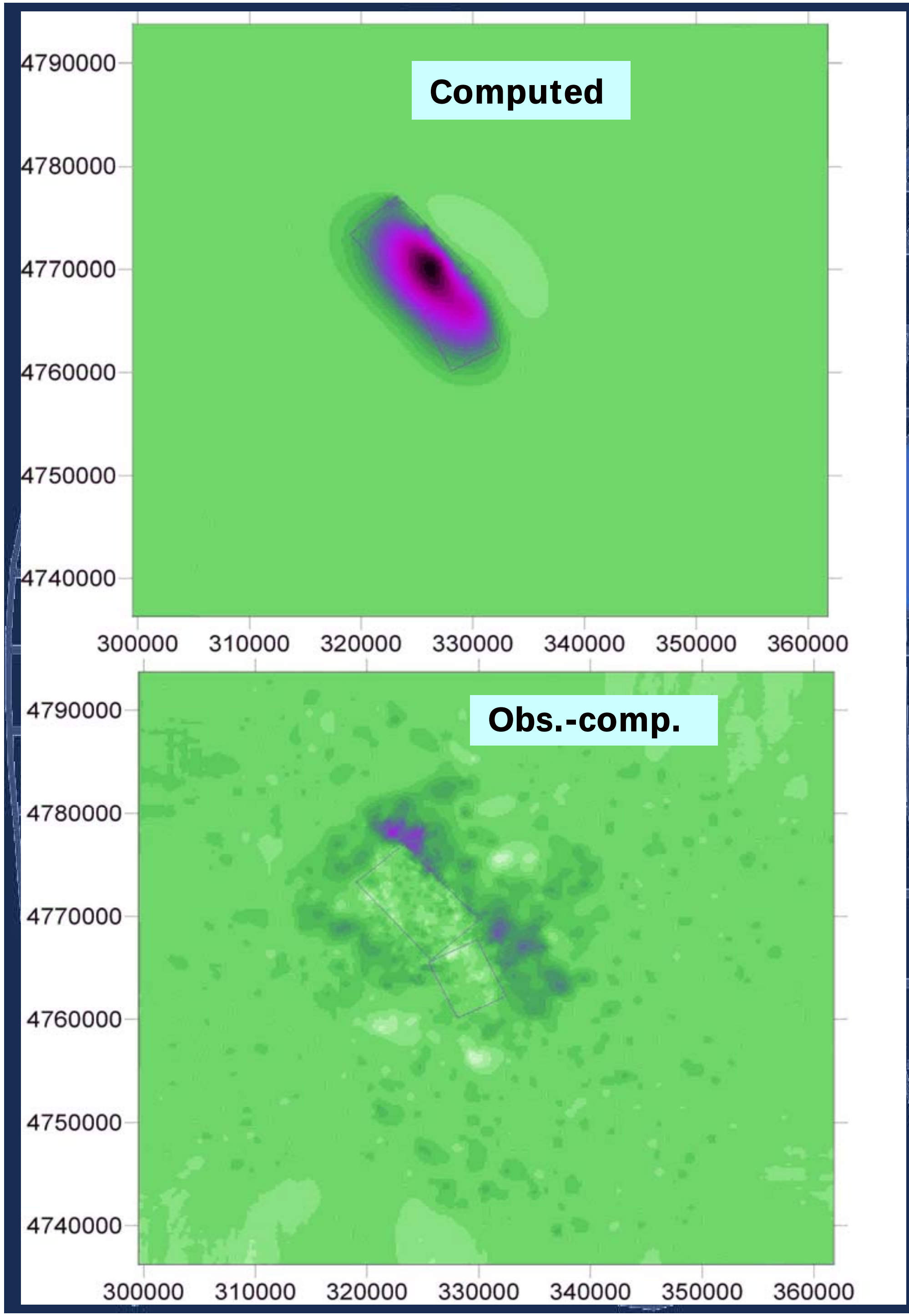
Permanent GPS observations

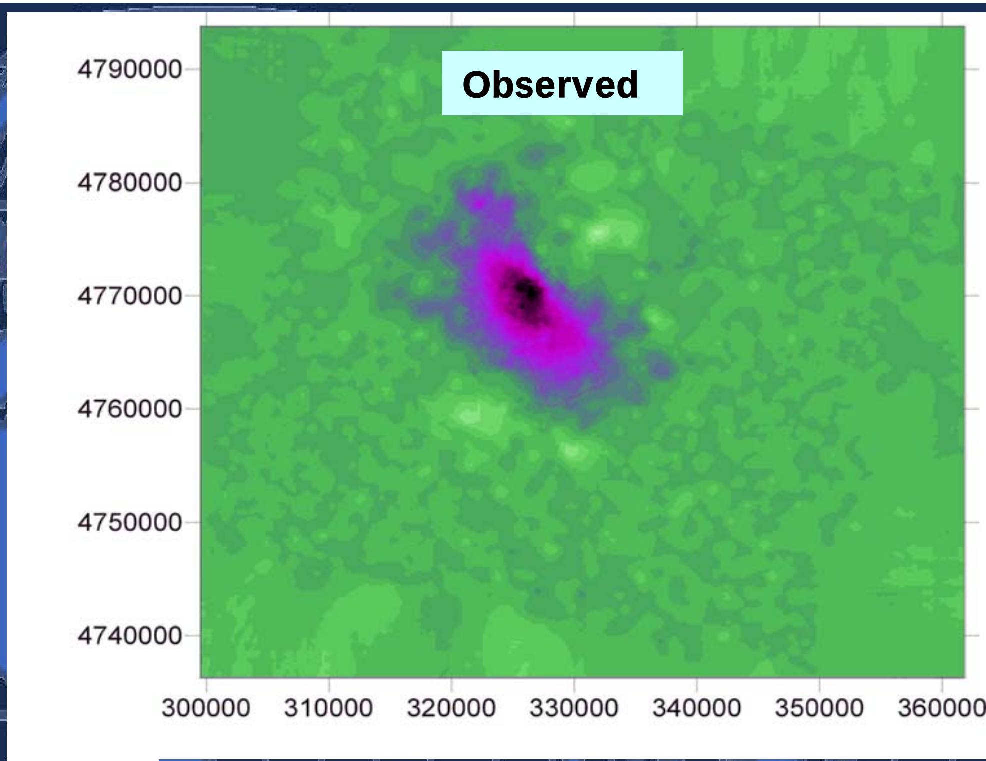
Methodology for detecting the vertical movements
during the pre-seismic, co-seismic and post-seismic phases
in earthquake prone areas

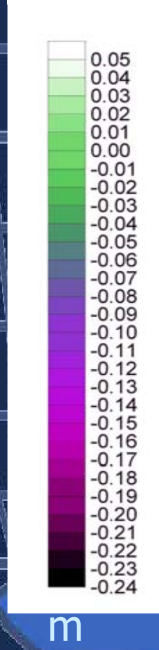




Colfiorito seismic sequence 1997







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.

Which is the contribution of Earth Observations?

- **Inter and pre-seismic phase:** monitoring of surface deformations, which is a possible indicator of stress build up on faults
- **Co-seismic phase:** improve understanding of the process taking place along the fault plane and permit estimating of the interactions of the stress field (modified after the seismic event) and nearby faults.
- **Post-seismic phase:** monitoring possible phenomena (e.g. afterslip, post-seismic relaxation) that may affect the stress field in the lithosphere

IDRiM: Integrated Disaster Risk Management

Why Integrated Disaster Risk Management (IDRiM) ?

- Disaster management for multiple hazards/disasters
- Disaster Management for multiple stakeholders in cities, regions and communities
- More participatory disaster risk management needed as a part of IDRiM governance
- Incorporating disaster management into urban/regional/community management
- Methodological framework for more cross-disciplinary, more policy and practice oriented
- **Implementation science** for IDRiM highly expected

N. Okada (IDRC Davos, 29 Aug., 2006)

Positive steps towards implementation:

An agreement has been signed among the Abdus Salam International Centre for Theorethical 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 time dependent seismic hazard maps are made available to the Civil Defence (end user).

united nations educational, scientific and cultural organization

international atomic energy agency

the **abdus salam** international centre for theoretical physics

REGIONE AUTONOMA FRIULI - VENEZIA GIULIA

PROTEZIONE CIVILE

zivilschutz

protection civile

civil defence

MEXT-NIED Project

International Framework for Development of Disaster Reduction Technology List on Implementation Strategies

- **Target Technologies**

  The mission of the project will be to compile disaster reduction technologies that will help enhance disaster reduction capabilities of developing countries. They should be affordable, sustainable, and be based on regional perspective.

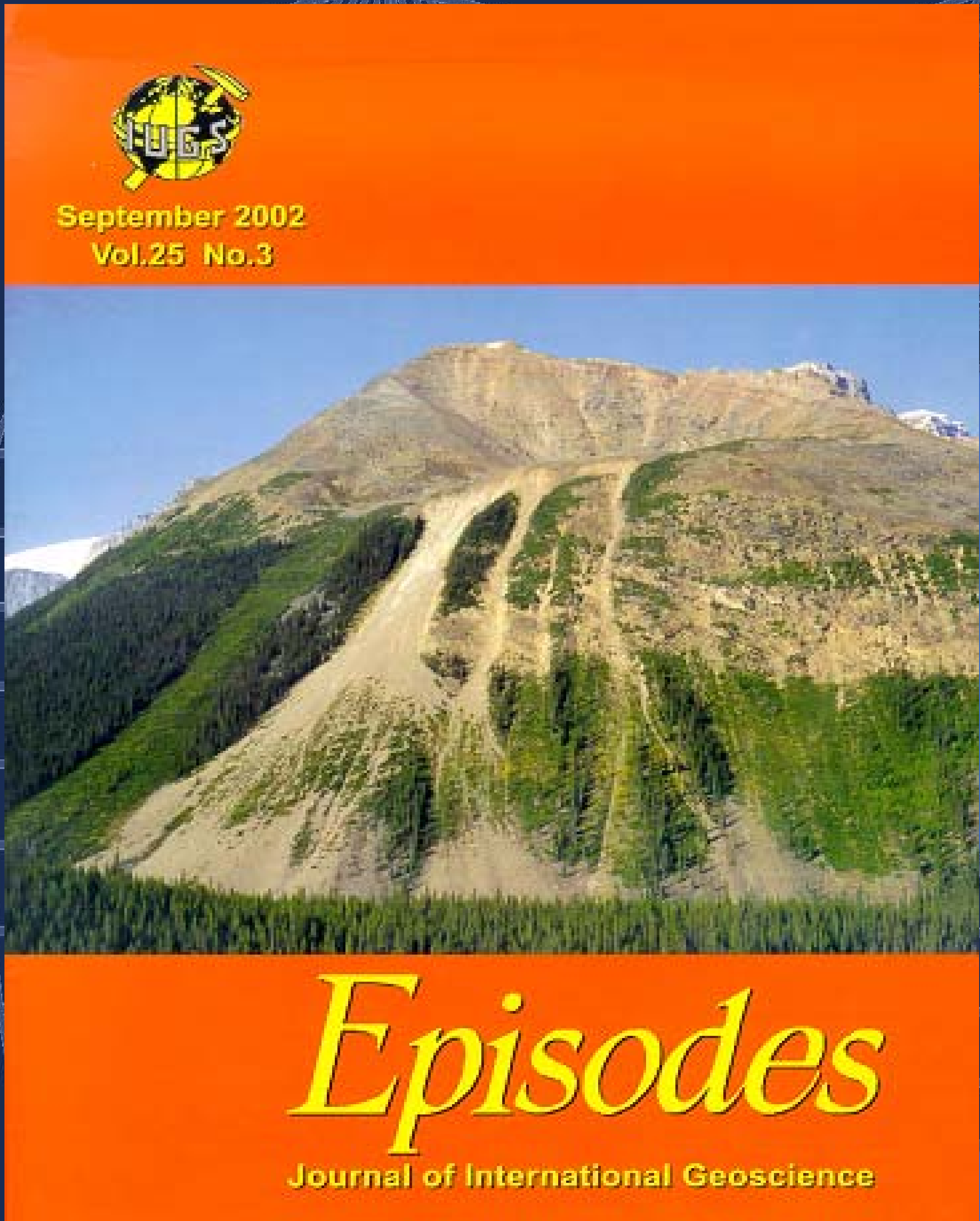
- **Implementation Oriented Technologies**

  Outputs from R&D efforts using modern research methodologies, but practiced under a clear notion of implementation strategies and international perspective throughout their planning, execution, and integration: not a one-sided show case of researchers, nor "research for research."

International Perspective

- At international level the **UNESCO-IUGS-IGCP** project **"Realistic Modelling of seismic input for Megacities and Large Urban Areas"**, thanks to an extensive use of the realistic modelling, permitted to define for several large cities worldwide, standardized **innovative maps** of the relevant parameters of ground motion.
- The relevant outcomes of the project have been published in 2002 on Episodes, the official journal of IUGS.

(http://www.ictp.trieste.it/www_users/sand/unesco-414.html)



Studied Cities:

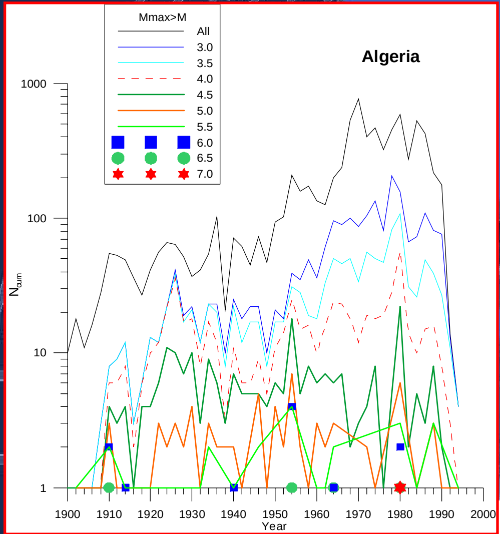
Algier
Bucharest
Cairo
Debrecen
Delhi
Naples
Bejing
Rome
Russe
Santiago de Cuba
Thessaloniki
Sofia
Zagreb

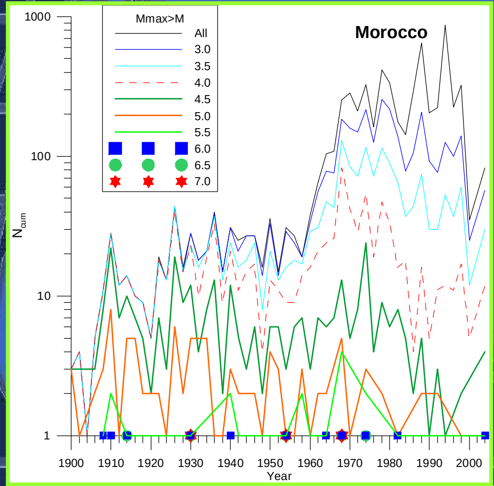
UNESCO-IUGS-IGCP Project 457

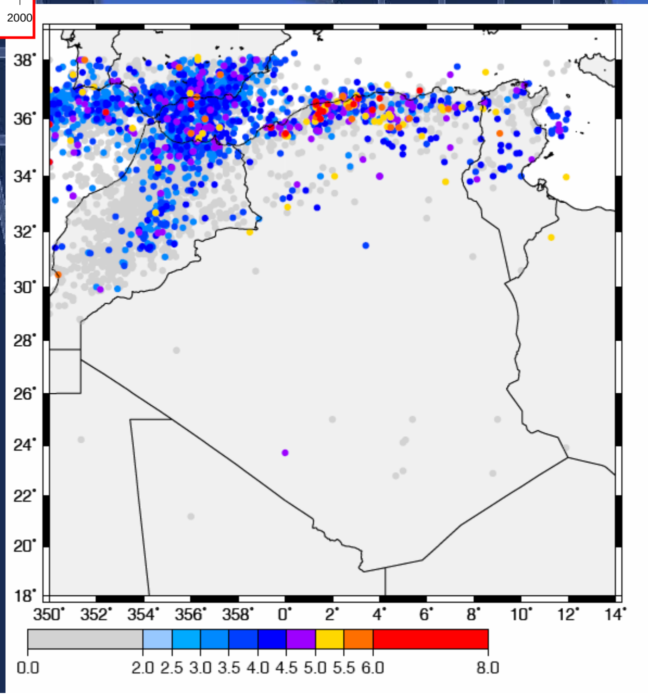
"Seismic Hazard and Risk Assessment in North Africa"

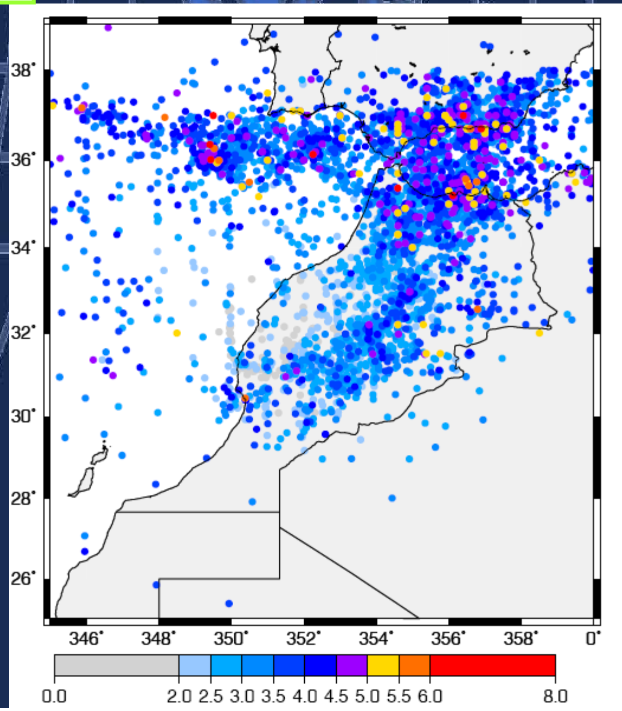
(Algeria, Libia, Morocco, Tunisia, Egypt, Italy)

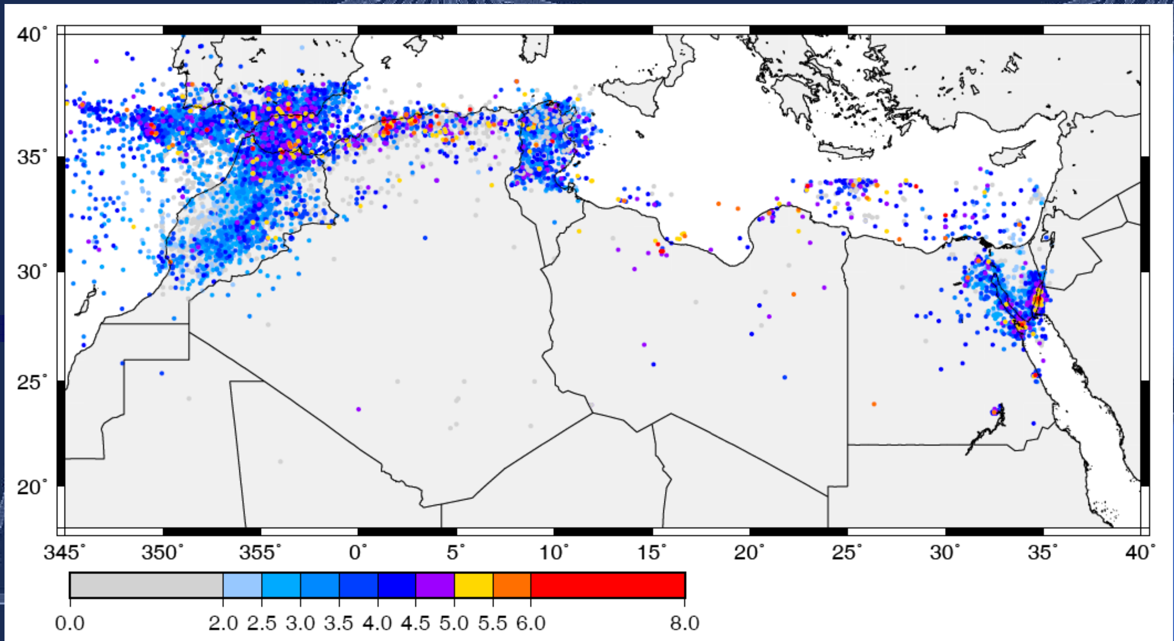
Compilation of a Unified Earthquake Catalog for Northern Africa



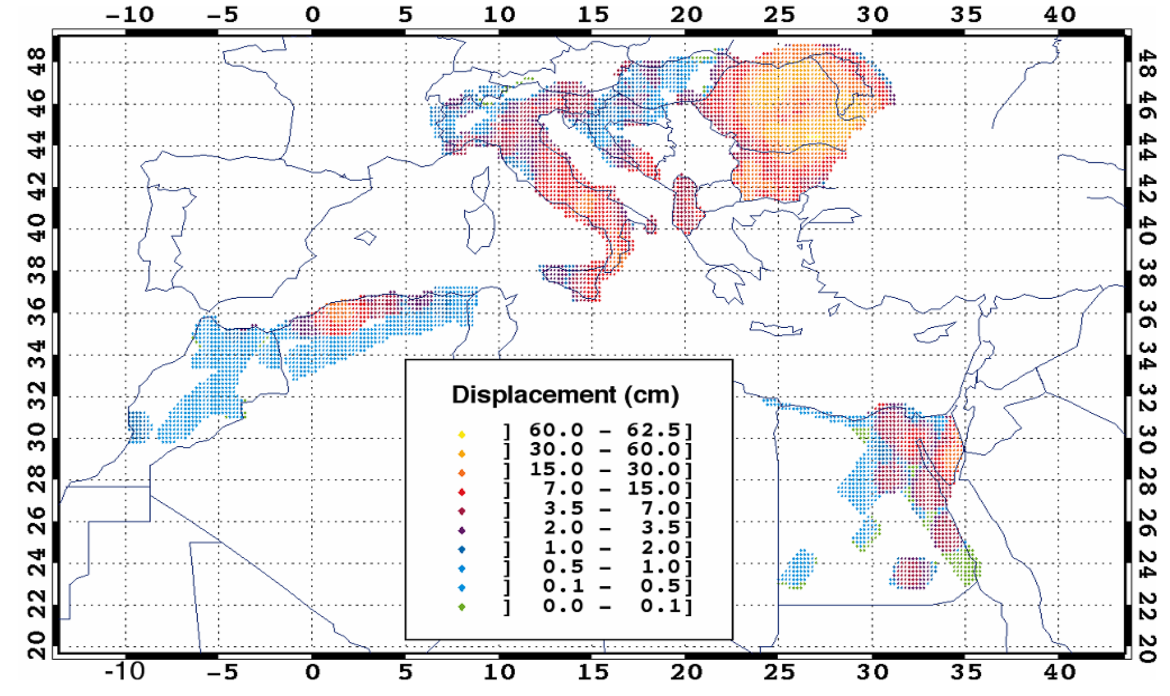








Deterministic seismic hazard assessment



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, earth observations and neo-deterministic seismic hazard procedures can be integrated, blending together the available information in 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).

Conclusions

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

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

- The seismic input (complete seismograms) provided by the realistic modeling of ground motion permits the engineering non-linear dynamic analysis of relevant structures (e.g. bridges, hospitals, dams) (*Field et al., 2000*).