The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2016-16

Joint ICTP/IAEA Advanced Workshop on Earthquake Engineering for Nuclear Facilities

30 November - 4 December, 2009

Real Time Testing of Integrated Ground Shaking Scenarios in Italy: the SISMA Prototype System

Antonella Peresan

University of Trieste/ICTP
Trieste

ICTP/IAEA Advanced Workshop
Earthquake Engineering for Nuclear Facilities
Trieste, Italy (November 30 – December 4 2009)

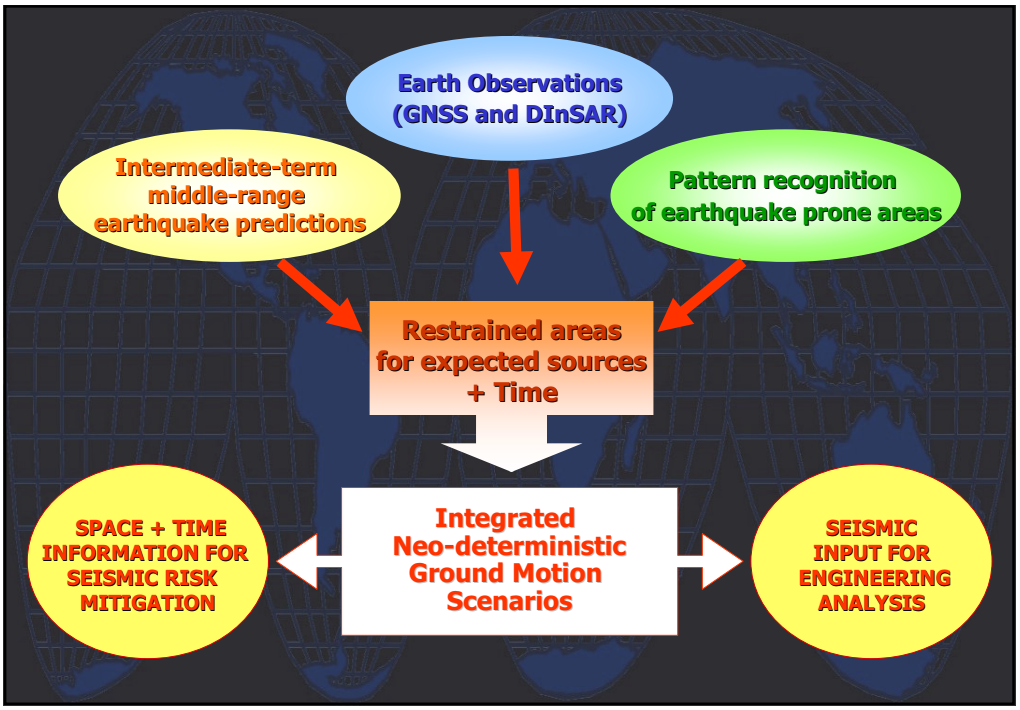
Real time testing of integrated ground shaking scenarios in Italy: the SISMA prototype system

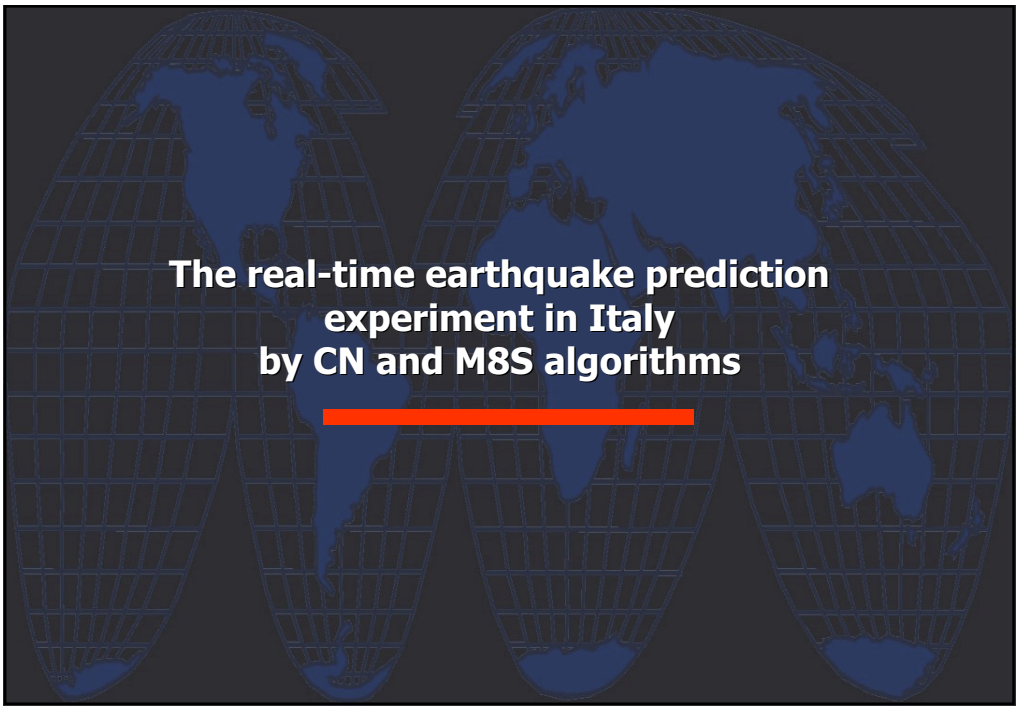
Antonella Peresan

Contributed:
F. Vaccari, E. Zuccolo, G.F. Panza, V. Kossobokov, L. Romashkova, A. Gorshkov
R. Sabadini, R. Barzaghi, A. Amodio, G. Bianco

Outline

- **Integrated neo-deterministic seismic hazard assessment:**
  - Real-time monitoring of the seismic flow
  - Evaluating prediction results
  - Pattern-recognition of earthquake prone areas
  - Time-dependent ground shaking scenarios
  - The Aquilano earthquake
- **The ASI-SISMA prototype system:**
  - General approach
  - System engineering
  - Products


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


The real-time earthquake prediction
experiment in Italy
by CN and M8S algorithms

Real-time monitoring of the seismic flow in the Italian Region and its surroundings

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

Main features:

- Fully formalized algorithms and software available for independent testing;
- Use of published & routine catalogs of earthquakes (e.g. NEIC);
- Worldwide tests ongoing for more than 15 years already permitted to assess the significance of the issued predictions.

Italy:

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

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

Intermediate-term middle-range earthquake prediction experiment in Italy

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

Updated predictions are regularly posted at:

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

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

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

Real-time monitoring of the seismic flow in the Adria Region and its surroundings

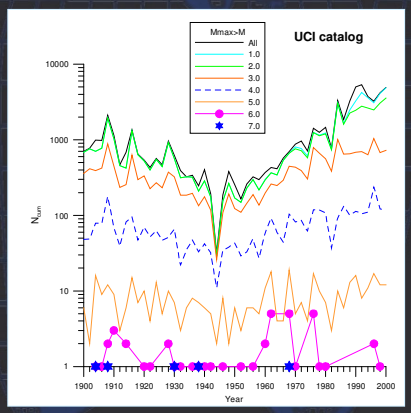
CN and M8S algorithms are based on a set of empirical functions of time to allow for a quantitative analysis of the premonitory patterns which can be detected in the seismic flow:

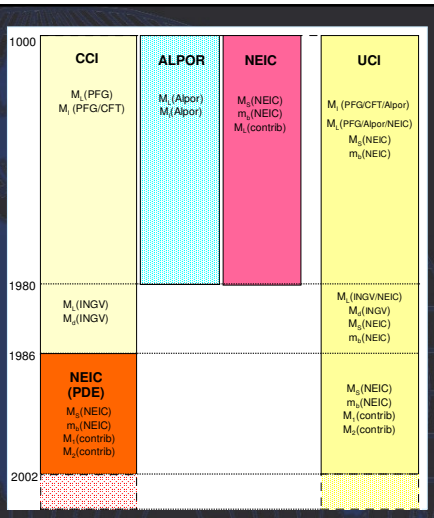
- Variations in the seismic activity
- Seismic quiescence
- Space-time clustering of events

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

CN and M8S algorithms in Italy: the input data

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

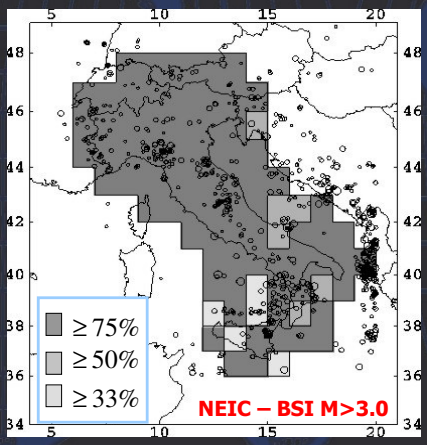


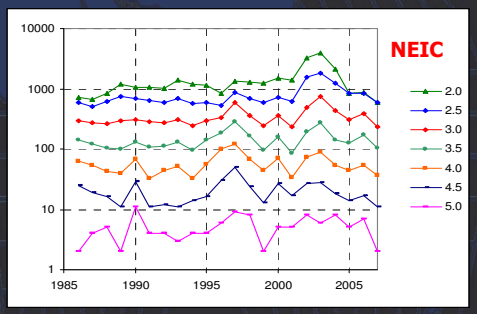


- Italian catalog (basically PFG and Alpor data) is used up to 1985, mainly to set up the algorithms parameters
- Global data from NEIC are used since 1986 to perform routine real time predictions

Analysis of spatial completeness

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



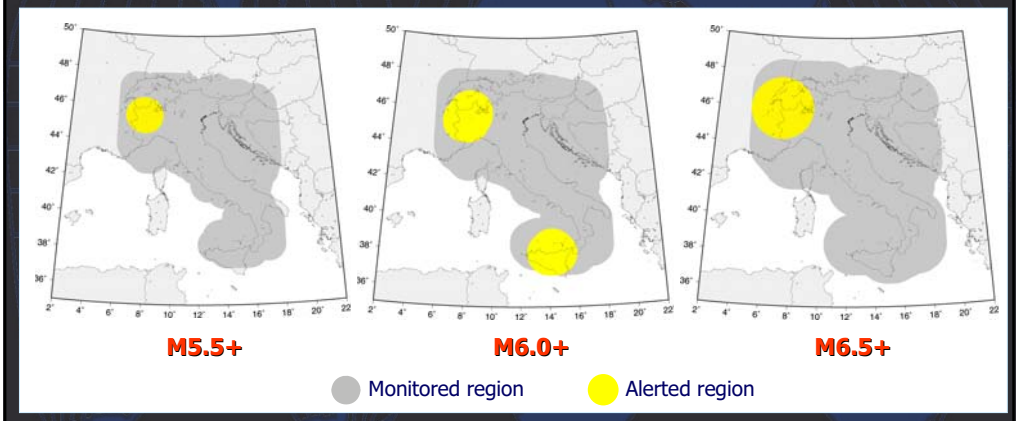


It is also found that the level of detection of magnitude 3.0 and even 2.5 earthquakes in NEIC catalog keeps rather stable in the period 1986-2007

L.Romashkova, lina@mitp.ru

Algorithm M8S in Italy

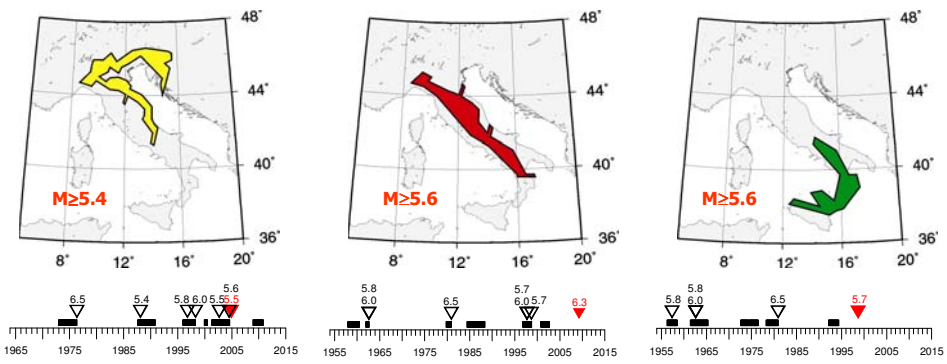
- Predictions for Italy are performed for three different magnitude ranges, namely M6.5+, M6.0+ and M5.5+, where M_0+ indicates the magnitude range: $M_0 \le M \le M_0+0.5$.



Updated to July 1 2009

Algorithm CN in Italy

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



Updated to November 1 2009

CN application to the Adriatic region

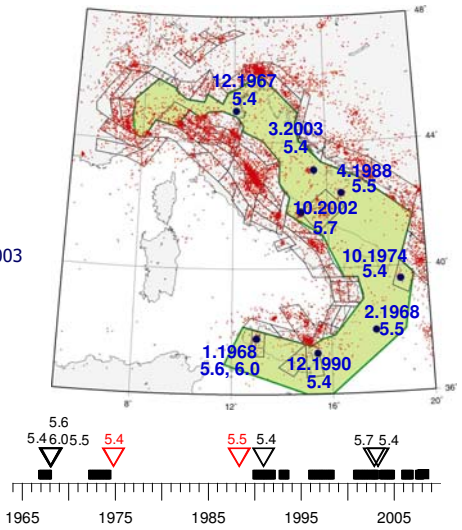
ADRIA REGION

Prediction of the events with M≥5.4

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

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

TIPs
Strong Earthquakes predicted
Failure to predict



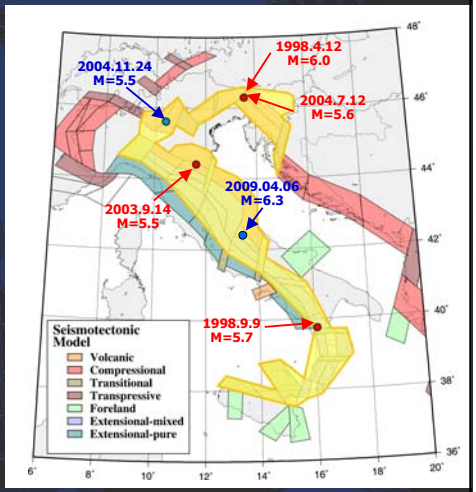
The CN real-time monitoring of seismic flow

Real-time testing 1998-2009

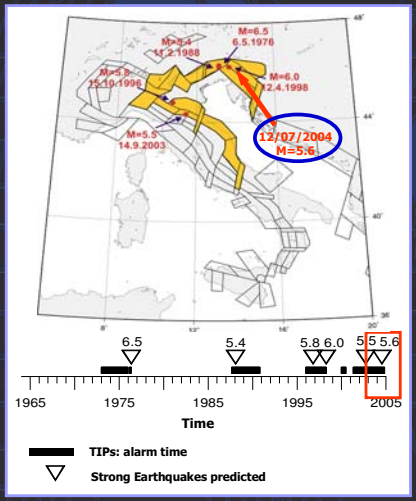
Earthquakes occurred within the space-time-magnitude volume monitored by CN since 1998

Date	Latitude, °N	Longitude, °E	Depth, KM	M	CN	Location
1998.04.12	46.24	13.65	10	6.0	Yes	Slovenia
1998.09.09	40.03	15.98	10	5.7	Yes	South Italy
2003.09.14	44.33	11.45	10	5.5	Yes	Near Bologna
2004.07.12	46.30	13.64	24	5.6	Yes	Slovenia
2004.11.24	45.63	10.57	24	5.5	No	North Italy
2009.04.06	42.33	13.33	9	6.3	No	Central Italy

Updated to November 1 2009 (next updating January 1 2010)



The CN real-time monitoring of seismic flow



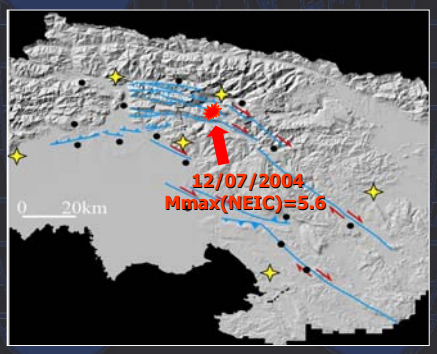
The Bovec earthquake - July 12 2004

Alarmed area for M≥5.4 by CN algorithm

(Peresan et al., ESR,2005)

(As on 1 July 2004)

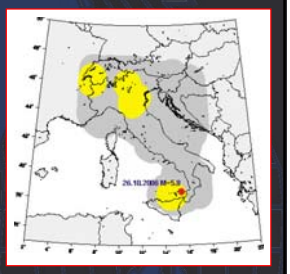
Southeastern Alps – External Dinarides
InSAR - CGPS - Campaign GPS monitoring

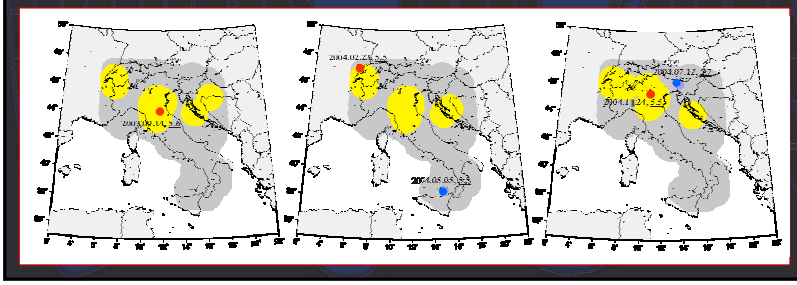


The M8S real-time monitoring of seismic flow

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

Date	Latitude, ^{0}N	Longitude, ^{0}E	Depth, KM	M_{max}	M8S	Location
2002.09.06	38.38	13.70	5	5.9	No	Near Sicily
2002.10.31	41.79	14.87	10	5.9	No	South Italy
2003.03.29	43.11	15.46	10	5.5	Yes	Adriatic sea
2003.09.14	44.33	11.45	10	5.6	Yes	Near Bologna
2004.02.23	47.27	6.27	17	5.5	Yes	Switzerland
2004.05.05	38.51	14.82	228	5.5	No	Near Sicily
2004.07.12	46.30	13.64	24	5.6	No	Slovenia
2004.11.24	45.63	10.57	24	5.5	Yes	North Italy
2006.10.26	38.67	15.40	216	5.8	Yes	Near Sicily





Monitored region

Alerted region

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

Updated to January 1 2009

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

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

Evaluating prediction results

Intermediate-term middle-range earthquake prediction

Space-time volume of alarm in M8S application in Italy

Experiment	M6.5+		M6.0+		M5.5+	
	Space-time volume, %	n/N	Space-time volume, %	n/N	Space-time volume, %	n/N
Retrospective (1972-2001)	36	2/2	40	1/2	39	9/14
Forward (2002-2009)	35	0/0	39	0/1	20	5/9
All together (1972-2009)	36	2/2	40	1/3	35	14/23

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

(updated to July 1 2009; next updating January 1 2010)

A complete archive of M8S predictions in Italy can be viewed at:
http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm
http://www.mitp.ru/prediction.htm

e-mail: lina@mitp.ru

Intermediate-term middle-range earthquake prediction

Space-time volume of alarm in CN application in Italy

Experiment	Space-time volume of alarm (%)	n/N	Confidence level (%)
Retrospective* (1954 – 1963)	41	3/3	93
Retrospective (1964 – 1997)	27	5/5	>99
Forward (1998 – 2009)	27	4/6	95
All together (1954 – 2009)	29	12/14	>99

* Central and Southern regions only

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

(updated to November 1 2009; next updating January 1 2010)

A complete archive of CN predictions in Italy can be viewed at: http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm

e-mail: aperesan@units.it

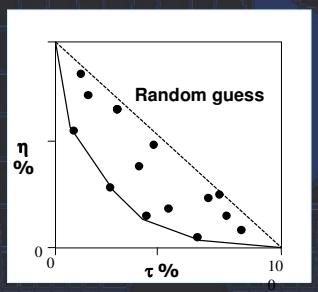
Intermediate-term middle-range earthquake prediction

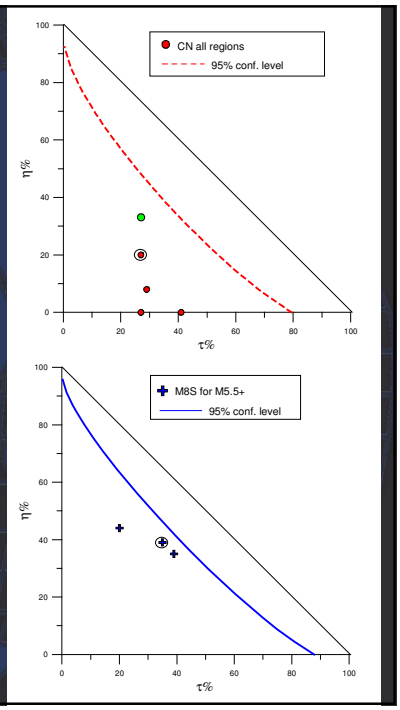
Evaluation of prediction results

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

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

τ : the space-time volume of alarm





CN and M8S predictions in Italy

Updated to November 1 2009 (next updating January 1 2010)

Evaluation of prediction results: CSEP Testing in Italy

The Collaboratory for the Study of Earthquake Predictability (CSEP) aims to provide a well controlled environment in which earthquake forecasts can be run and evaluated.

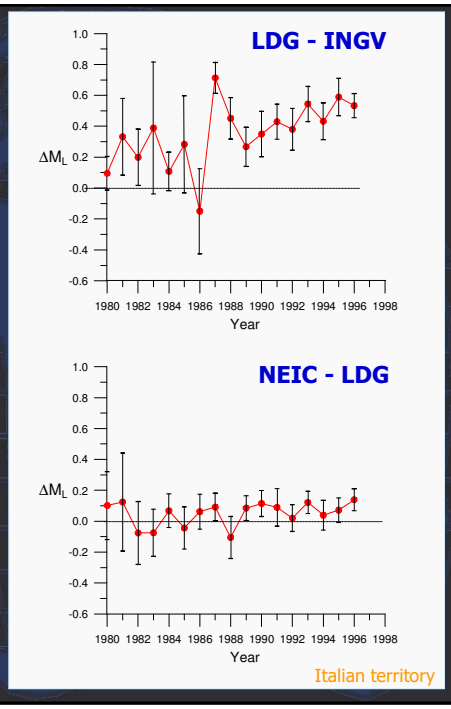
The Italian testing region: Rules of the Game and some basic shortcomings

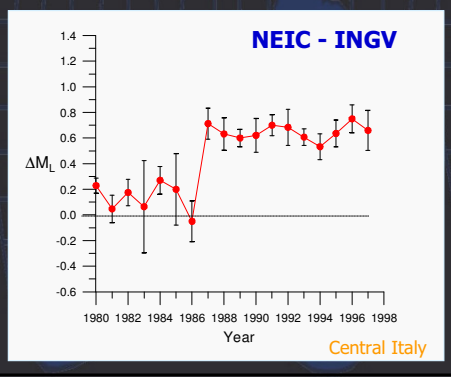
1. **Errors in the input data.** *"Models will be evaluated against the authoritative observed data supplied by INGV [...]. The INGV ML magnitude scale will be considered the reference scale for model development and testing."*
2. **Missing methods/criteria to compare** different alarm-based models and to compare alarm-based models with probability-based models.
3. **Short testing time interval:** five years testing could be too short to reach any conclusion about the effectiveness of predictions for the largest earthquakes.
4. **Non real-time predictions.** *"Tests are performed with a delay of 30 days relative to real-time, in order for the authoritative data to be manually revised and published."*
5. **Independency** amongst testing centers, data providers and modelists should be guaranteed

Local magnitude comparison: Italian territory

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

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





"Il confronto con le procedure attualmente in uso presso la RSNC ha confermato che queste tendono a sottostimare alle magnitudo elevate (fino a 0.5 unità per M>5.0) e a sovrastimare alle basse (circa 0.2-0.3 unità per M< 2.5)"

Rivalutazione della magnitudo per i terremoti italiani nel periodo post 1980

P. Gasperini G. Vannucci e L. Orlanducci

"Catalogo strumentale dei terremoti Italiani dal 1981 al 1996"

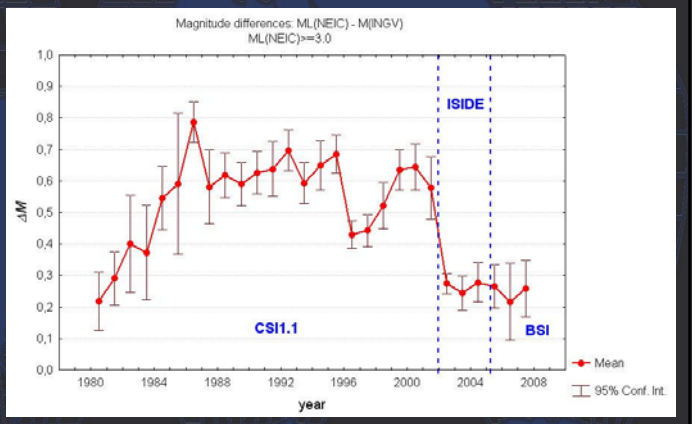
Versione 1.0 – **5.3.2001**

Local magnitude comparison: CSEP testing region

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

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

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

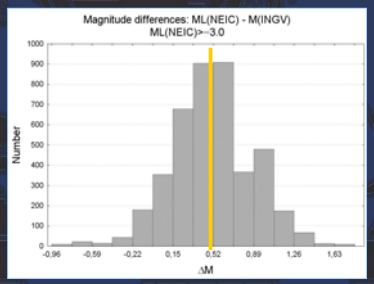


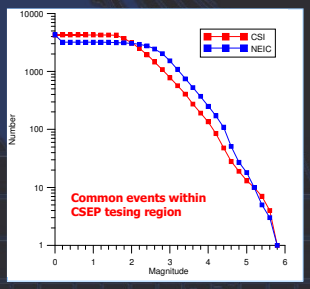
CSI1.1.- Castello, B., et al. (2007). Bull. Seism. Soc. Am. 97(1B): 128-139.

Local magnitude comparison: CSEP testing region

M_L(NEIC) – M_L(CSI)
1986-2002

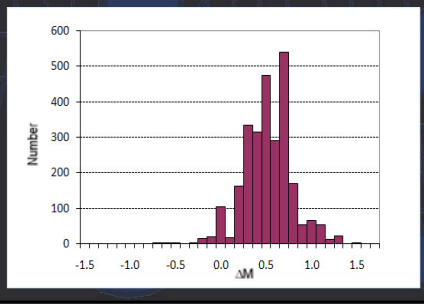
An average M_L(CSI) underestimation of ≈ 0.5-0.6 is identified for events with M≥3





M(INGV/ISIDE) – M(INGV/CSI)
2002

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

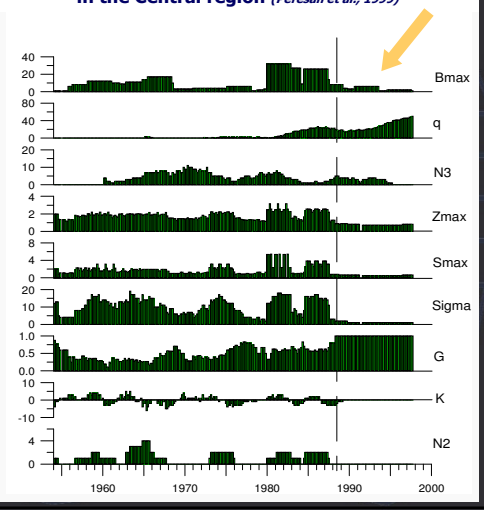


CSEP testing in Italy: errors in the input data

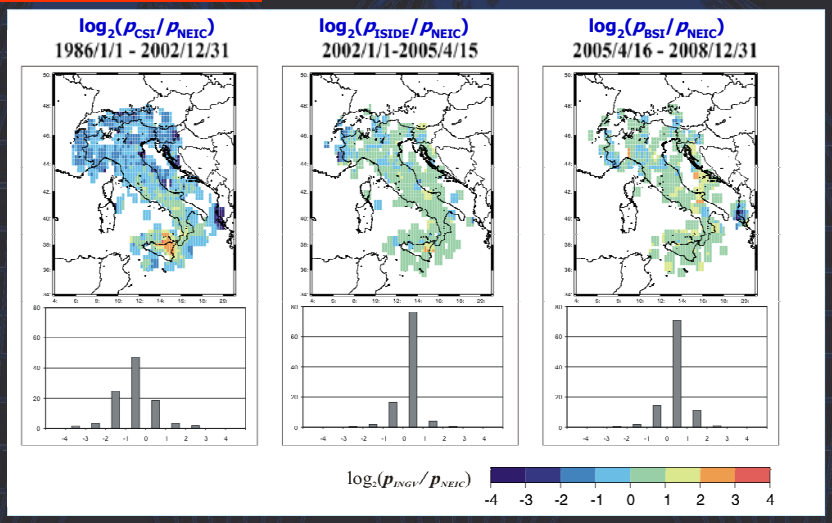
Existing heterogeneities in the input catalog may significantly affect any related characterization of seismicity and thus the detection of premonitory patterns

Effect of local magnitude underestimation on the standard CN functions

Time diagrams of the standard CN functions in the Central region *(Peresan et al., 1999)*



Spatial distribution analysis



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

CSEP testing in Italy: errors in the input data

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

Evaluation of prediction results: examples of biased assessment

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

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

No systematic formal analysis of prediction results

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

input data: 1950-2002

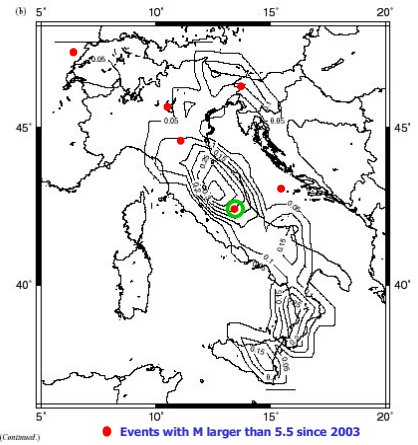


Figure 6. (*Continued.*)

(Faenza, Marzocchi & Boschi, GJI 2003)

Evaluation of prediction results: examples of biased assessments

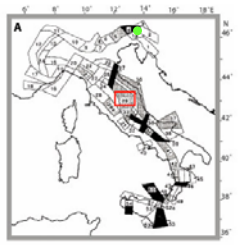
Neglecting evident failures creates the impression of high efficiency…

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

Marzocchi (Annals of Geophys, 2008)

process modeled through a Poisson process.

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



B

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

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

Pattern Recognition of Earthquake Prone Areas

Pattern Recognition of Earthquake Prone areas

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

⬇

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

Pattern Recognition of Earthquake Prone areas

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

Pattern Recognition of Earthquake Prone areas

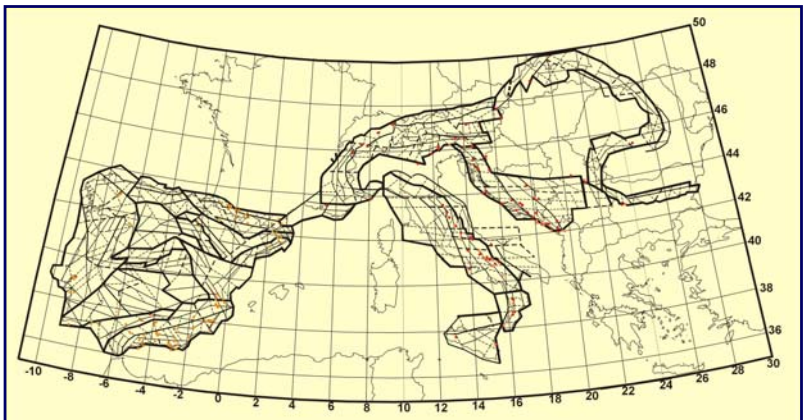
- **The Earthquake Prone Areas are identified evaluating, among the others, the following topographic characteristics :**
  - **Elevation and its variations in mountain belts and watershed areas;**
  - **Orientation and density of linear topographic features;**
  - **Type and density of drainage pattern.**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

Pattern Recognition of Earthquake Prone areas

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

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

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



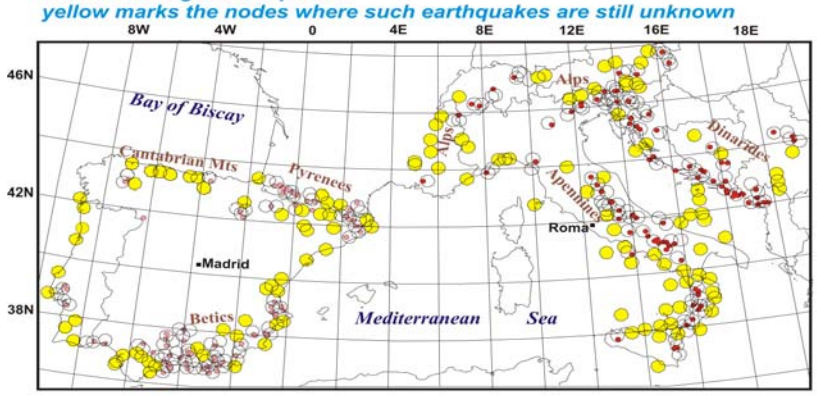
Morphostructural Zonation Map

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



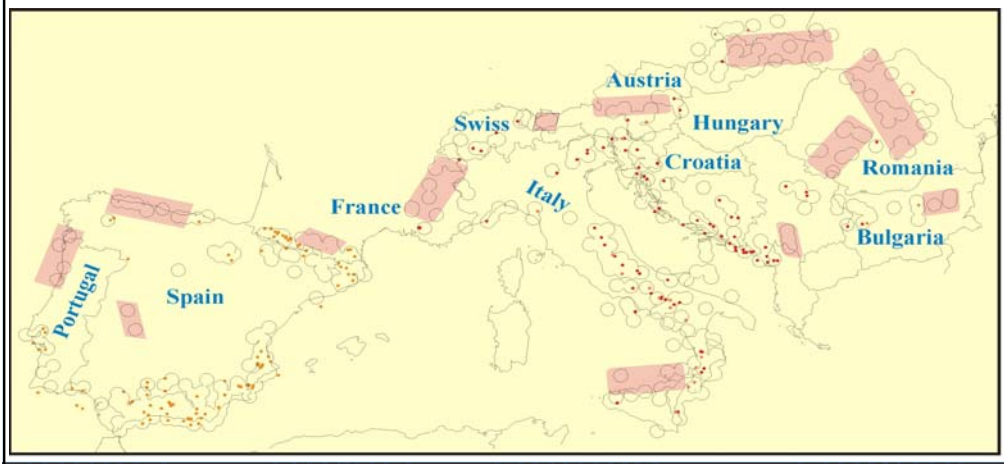
References
Gorshkov A.I., Panza G.F., Soloviev A.A. & Aoudia A. (2002). Morphostructural zoning and preliminary recognition of seismogenic nodes around the Adria margin in peninsular Italy and Sicily. *JSEE:* Spring 2002, 4, No.1, 1-24.
Gorshkov A.I., Panza G.F., Soloviev A.A., Aoudia A. (2004). Identification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

"Seismological database for seismic hazard assessment needs to be uniform and to cover a long enough time interval to allow the occurrence of rare, large-magnitude events — generally associated with long return periods — to be estimated, notably for critical structures."

(IAEA – ICTP "Workshop on the Conduct of Seismic Hazard Analyses for Critical Facilities" Trieste, May 2006)

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

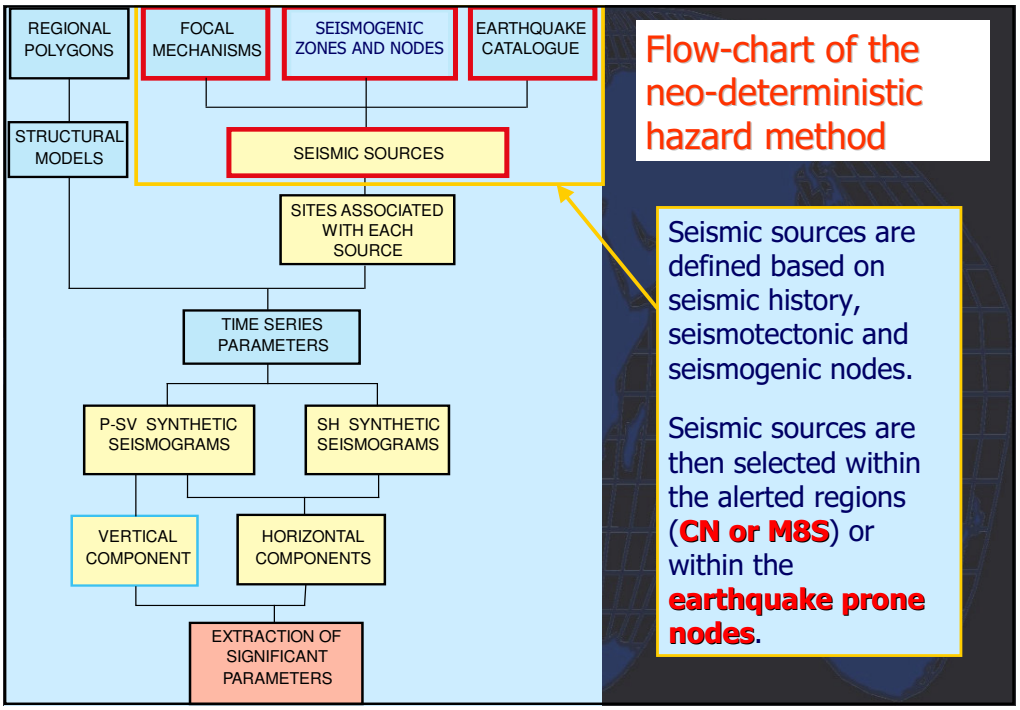
Is the information on observed seismicity sufficient to identify the sites where large earthquakes may occur?

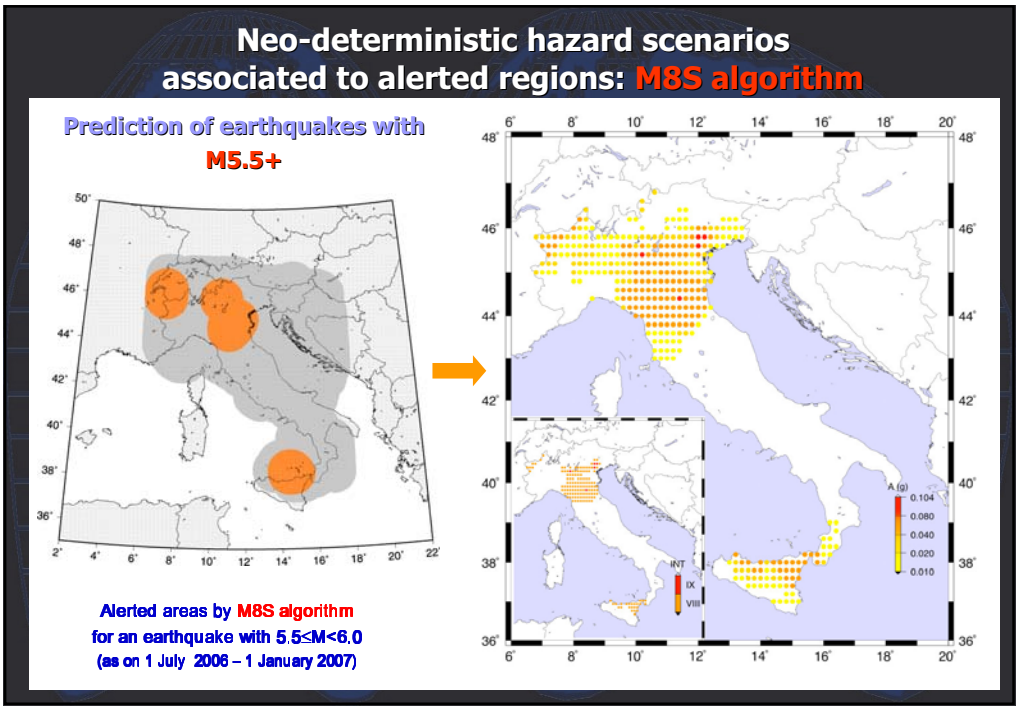


Integrated Neo-deterministic Hazard Scenarios

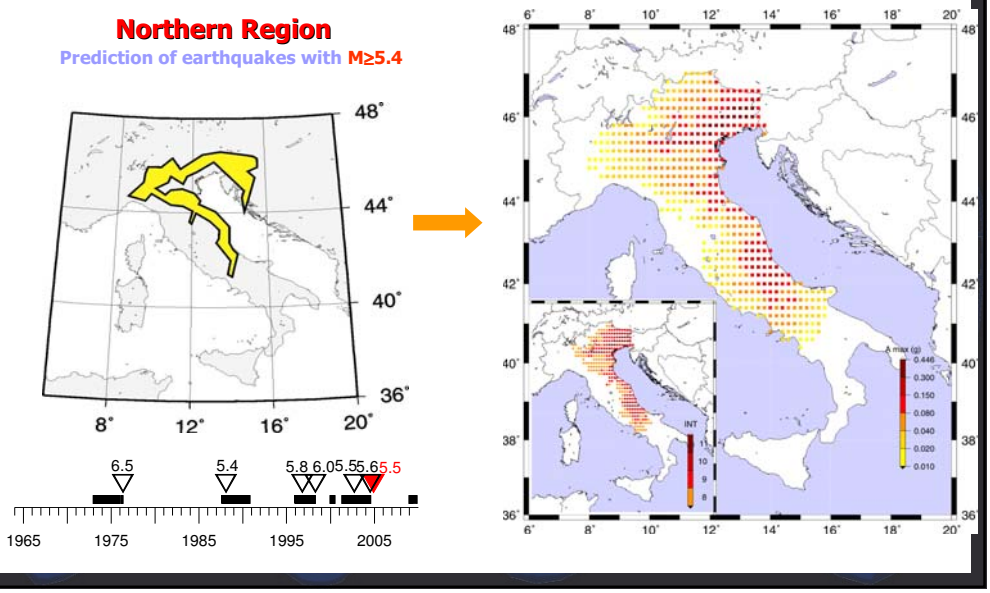
Regional ground shaking scenarios
(ground motion at bedrock)

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


REGIONAL POLYGONS
FOCAL MECHANISMS
SEISMOGENIC ZONES AND NODES
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 neo-deterministic hazard method
Seismic sources are defined based on seismic history, seismotectonic and seismogenic nodes.
Seismic sources are then selected within the alerted regions (CN or M8S) or within the earthquake prone nodes.


Neo-deterministic hazard scenarios associated to alerted regions: M8S algorithm
Prediction of earthquakes with M5.5+
Alerted areas by M8S algorithm
for an earthquake with 5.5≤M<6.0
(as on 1 July 2006 – 1 January 2007)

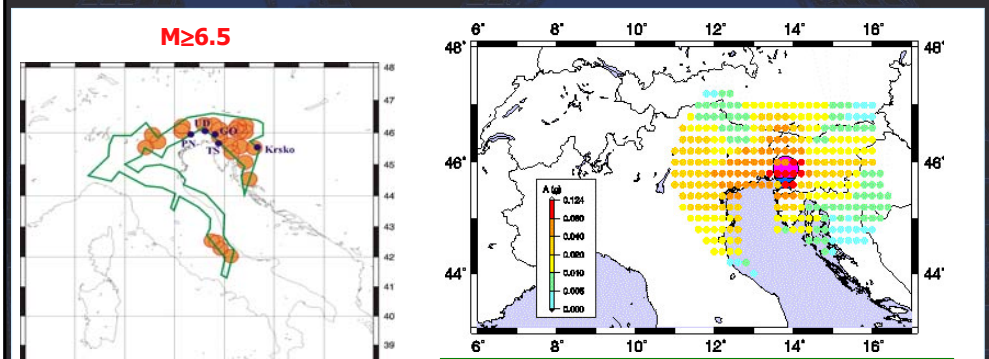
Neo-deterministic hazard scenarios associated to alerted regions: CN algorithm



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)



PGD (cm)	PGV (cm/s)	DGA (g)	I_{max} computed		I_{max} observed
			ING	ISG	
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.

Integrated Neo-deterministic Hazard Scenarios

Seismic Microzoning

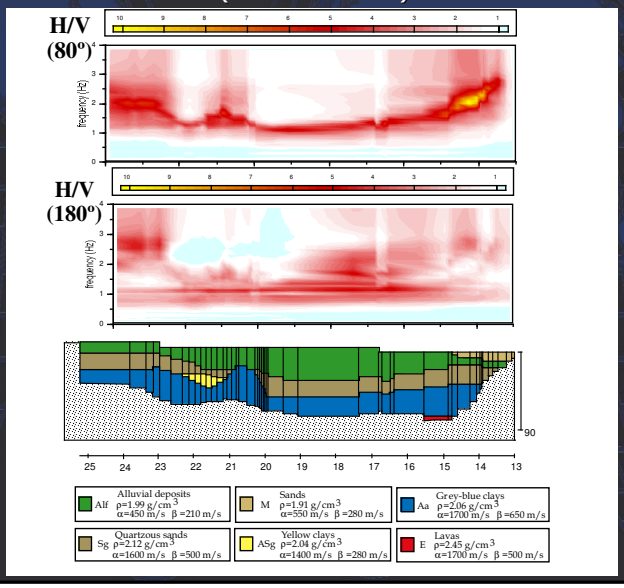
(including lateral heterogeneities and local soil conditions)

Site effects

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).

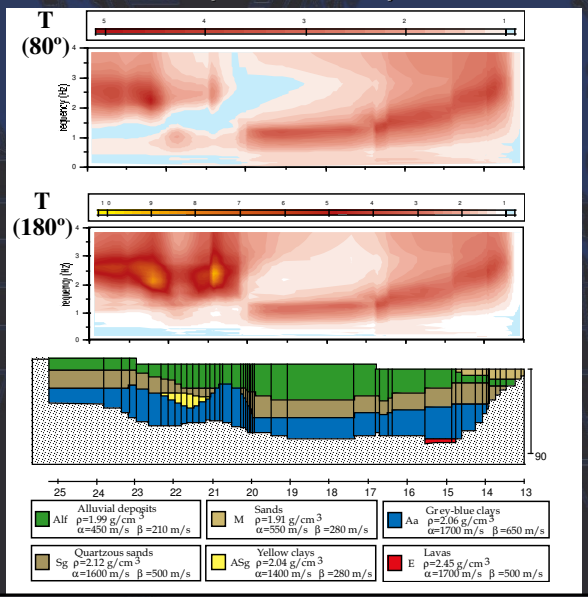
- **H/V:** is the spectral ratio between the horizontal and vertical components of motion.
- **RSR:** is the ratio between the amplitudes of the response spectra, for 5% damping, obtained considering the bedrock structure, and the corresponding values, computed taking into account the local heterogeneous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

Modeling of seismic input
(azimuth effect)



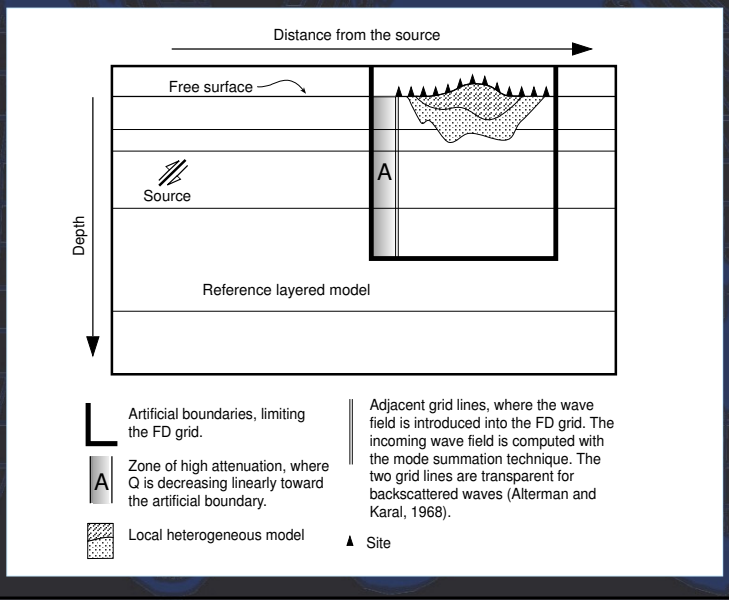
H/V spectral ratio

Modeling of seismic input
(azimuth effect)



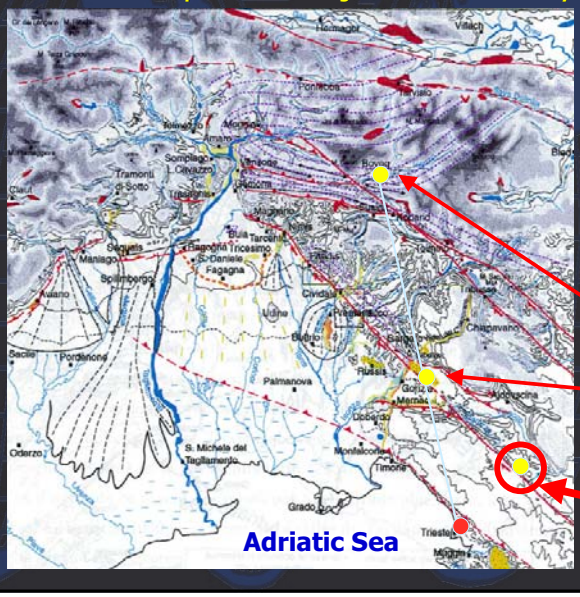
RSR for the SH component of motion

Hybrid Method: Modal Summation+Finite Differences



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)

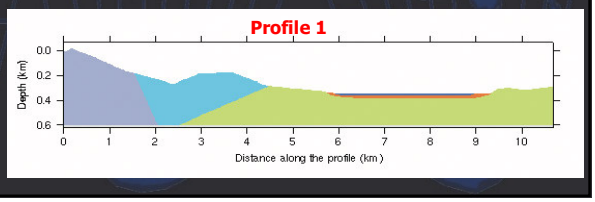
The closest seismic source at 17 km from Trieste (within Adria region)

Definition of the local model

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

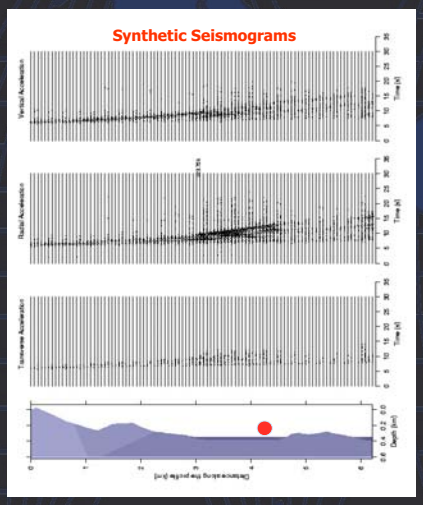
- Roiano - Palazzo Carciotti (1)
- DST - Palazzo Carciotti (2)
- Zona Industriale (E)

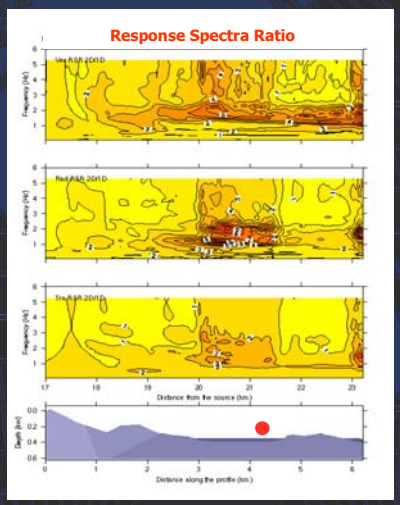
	Descr.	Rho	Vp	Qp	Vs	Qs
	Aria	0.000	0.000	0	0.000	0
	Riporti	1.800	0.420	30	0.200	15
	Sed. marini	1.900	0.800	40	0.400	20
	Flysch	2.000	1.800	100	1.000	50
	Arenarie	2.100	2.000	200	1.200	100
	Calcari	2.300	2.500	200	1.400	100



Detailed scenario of ground motion including local site effects

Example: scenarios of ground motion in the city of Trieste





Profile 1 - Bedrock "B" - Dist. 17 km - M=6.0
Accelerations and Amplifications (RSR 2D/1D)

Engineering analysis

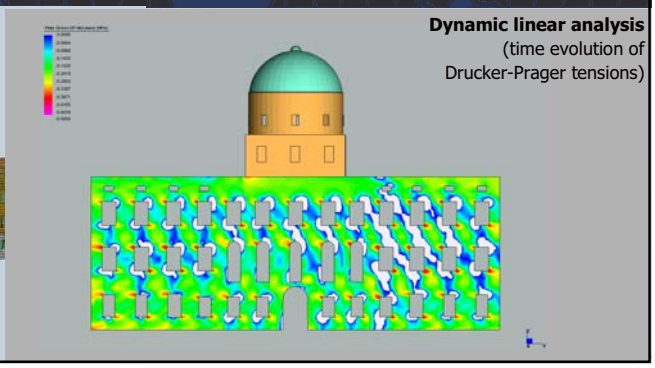
- The data set of synthetic seismograms can be fruitfully used and analysed by civil engineers for design and reinforcement actions, and therefore supply a particularly powerful and economical tool for the prevention aspects of Civil Defence.
- Non-linear dynamic analysis is possible considering the seismic input provided by the complete synthetic accelerograms as obtained from microzoning ⇒ 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)

Dynamic analysis

Model



Dynamic linear analysis
(time evolution of Drucker-Prager tensions)

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.

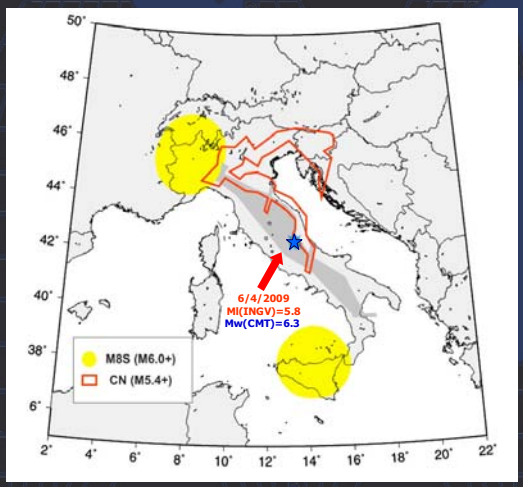
Routinely updated CN and M8S predictions, as well as the related hazard maps, are made available to the Civil Defence of the Friuli Venezia Giulia Region since 2006.

The Abdus Salam International Centre for Theoretical Physics

PROTEZIONE CIVILE

The Aquilano earthquake
6th April 2009

The Aquilano earthquake, 6th April 2009



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

CN Algorithm

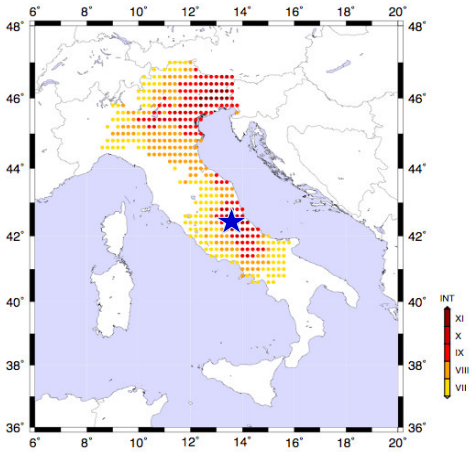
- The L'Aquila earthquake turns out to be a failure to predict within the Central Region
- The epicenter was about 10 km outside the alarmed CN territory (TIP declared for M≥5.4 within Northern region from 1.3.2009 to 1.3.2010)

M8S Algorithm

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

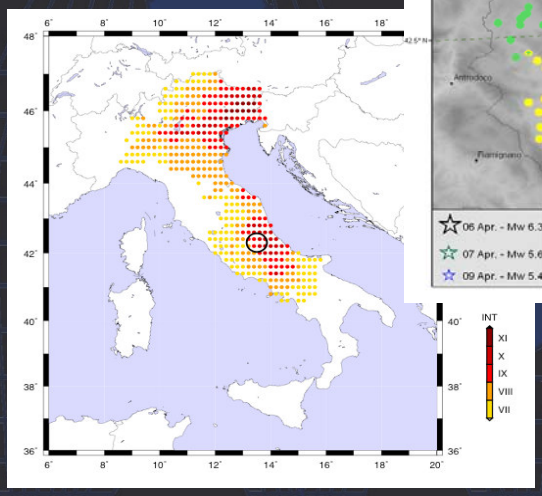
The Aquilano earthquake, 6th April 2009

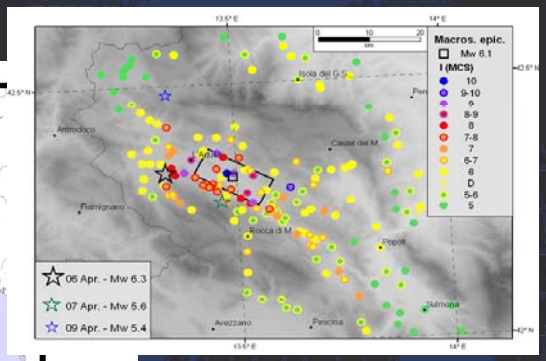
Alarmed polygon (red line) identified by CN algorithm for the period 1 March 2009 – 1 May 2009. The star indicates the epicenter of the 6 April 2009 event.



Scenario of MCS intensity associated with the alarmed area, as defined for the period 1 March 2009 – 1 May 2009. The epicenter is indicated by the blue star

The Aquilano earthquake, 6th April 2009

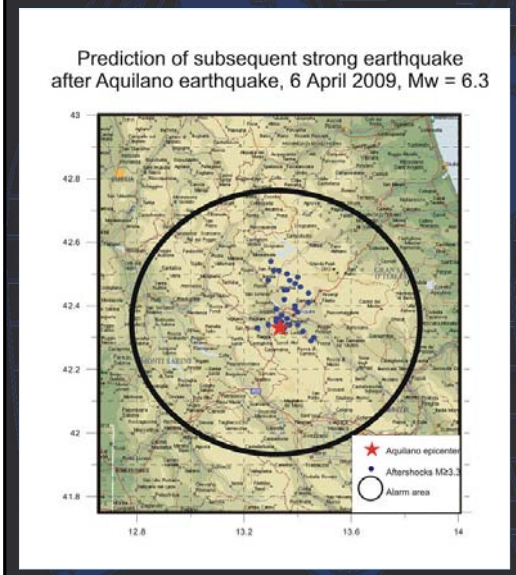




QEST-Rapporto sugli effetti del terremoto aquilano del 6 aprile 2009 [RPT03 – 20.04.2009]

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

Prediction of Subsequent Strong Earthquake in Central Italy



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

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

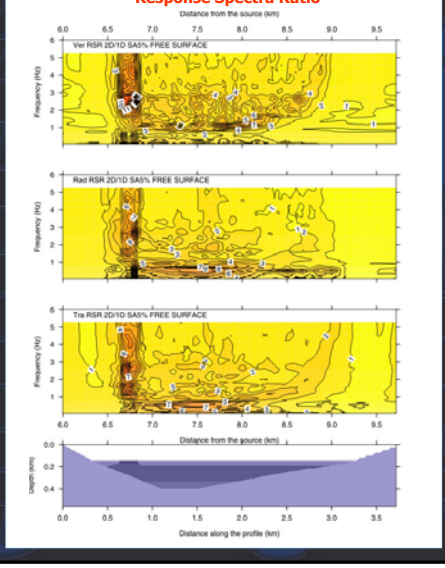
The algorithm is applied using the preliminary data from NEIC and INGV.

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

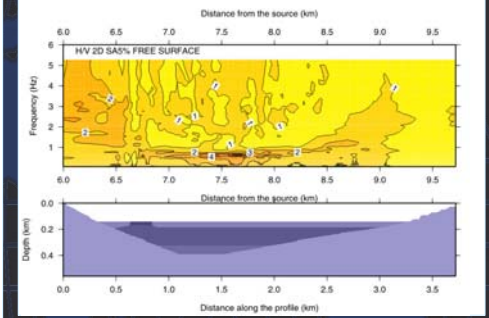
Detailed scenario of ground motion including local site effects

Example: scenarios of ground motion in the city of L'Aquila

Response Spectra Ratio



Rapporto H/V



The ratio H/V, based on the same synthetic seismograms, does not allow to evidentiate the relevant amplifications associated with low velocity sediments (Aterno river).

2D Model from *De Luca et al. (2005). BSSA, 95, 1469–1481*

F. Vaccari, vaccari@units.it

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.

Description of the Project

SISMA → Seismic Information System for Monitoring and Alert

- SISMA is a three year Pilot Project funded by the Italian Space Agency;
- Aim of the project is the development of a prototype system to support the Civil Defence (*End User*) in the decisional process for the management of the seismic risk in Italy;
- SISMA is organized in three subsequent versions, scaling down from national scale to local scale;
- The pre-operative demonstration phase, including real-time updating of products, started in May 2009.

SISMA Deterministic Approach

SISMA innovative approach towards the understanding of earthquake generation process builds over three major objectives:

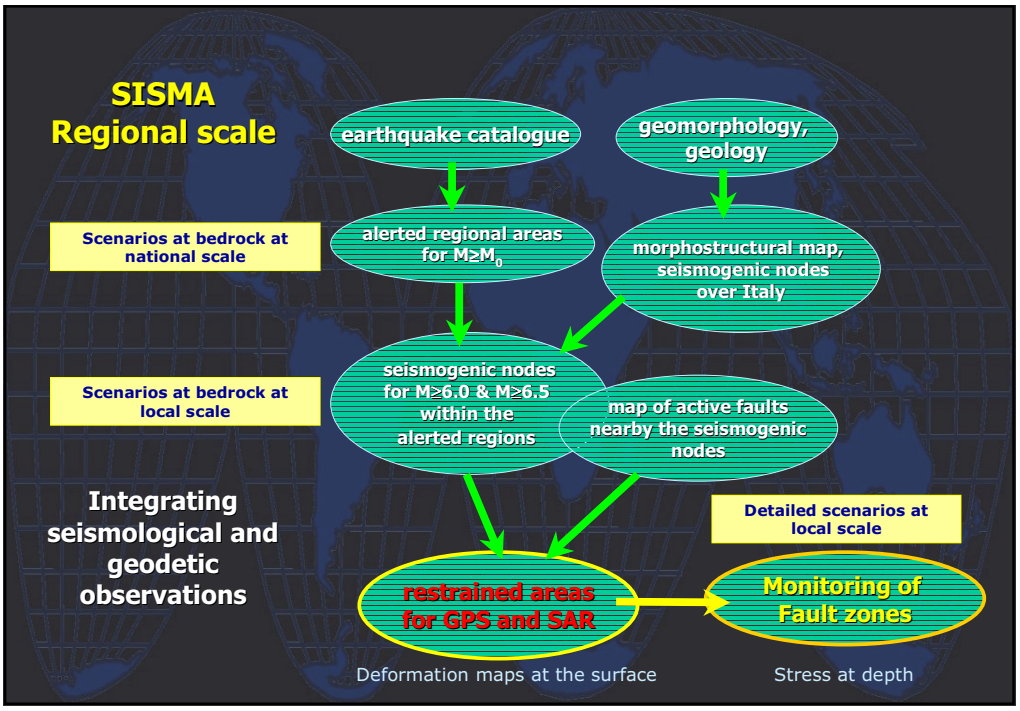
1) To take advantage of new generation of SAR satellites systems and of GNSS deformation data at the Earth's surface, in association with seismic flow monitoring

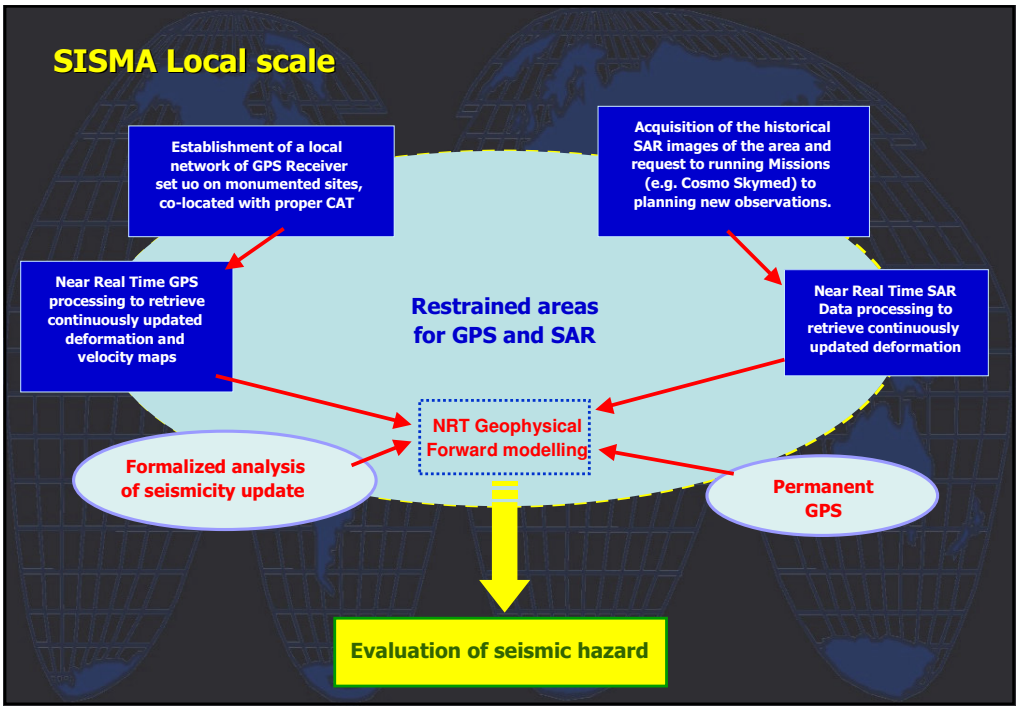
2) To develop an integrated geophysical, geodetic and seismological scheme to disclose stress built up within active faults for a deterministic approach of earthquake cycle description

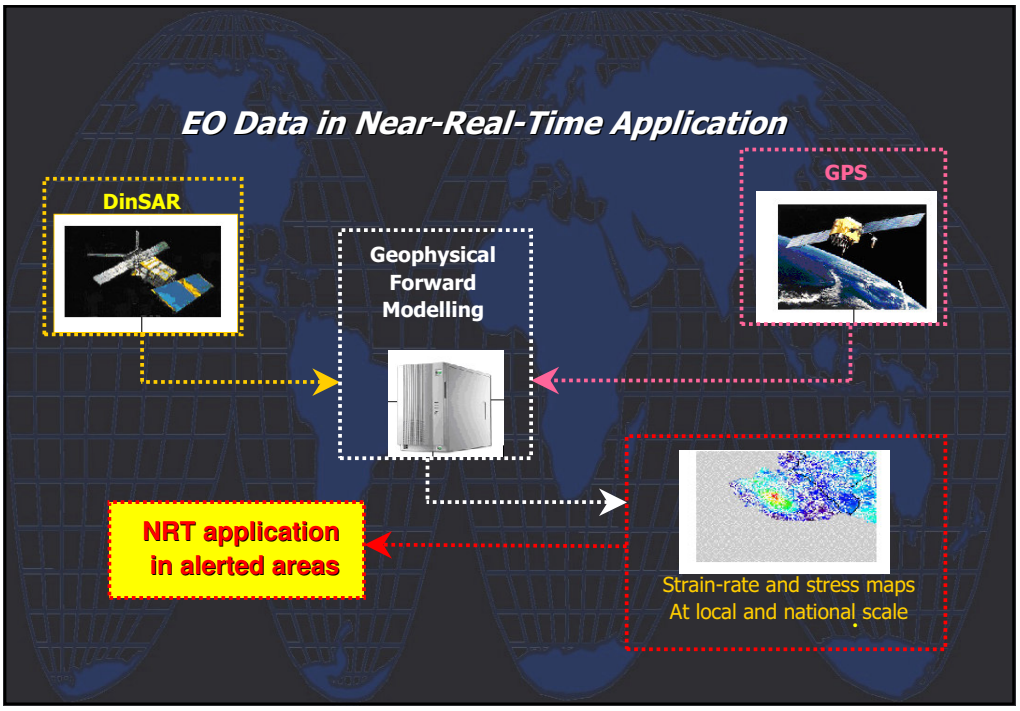
3) To overcome the shortcomings of the traditional methods for seismic hazard assessment, based on a purely probabilistic approach.

SISMA Overall Description

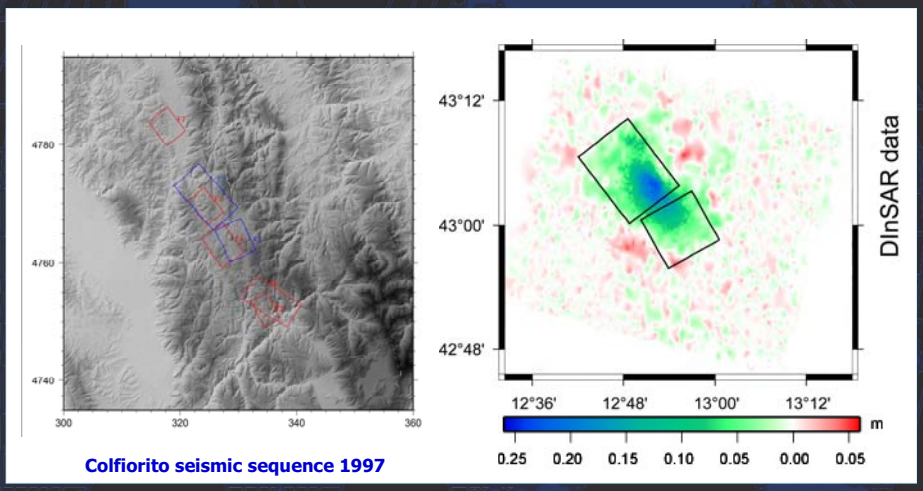
- Maps of alerted areas, prone to earthquake events with given magnitude, are obtained through comparison of non-EO information, provided by seismological data analysis, and taking into account results provided by Geophysical Modelling based on EO information;
- EO observations, consisting of GPS and 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.

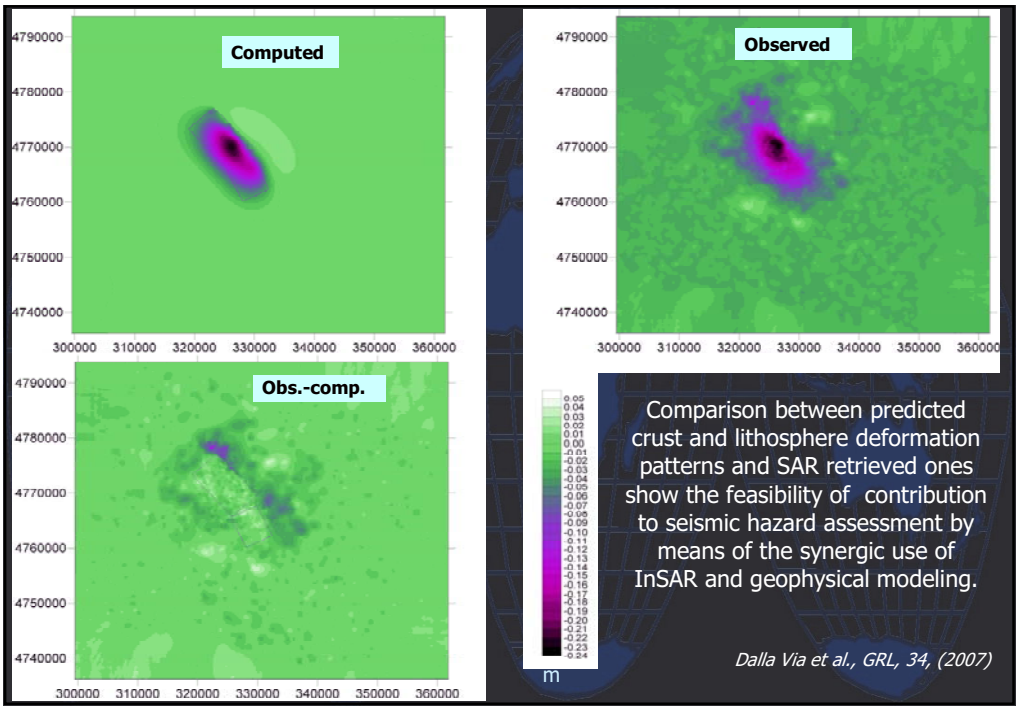



SISMA Local scale
Establishment of a local network of GPS Receiver set uo on monumented sites, co-located with proper CAT
Acquisition of the historical SAR images of the area and request to running Missions (e.g. Cosmo Skymed) to planning new observations.
Near Real Time GPS processing to retrieve continuously 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


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

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





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

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

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

Selected Test Areas

Friuli-Venezia Giulia → inter-seismic phase

Pollino (Calabria) → pre-seismic phase

Where surface deformations are a possible indicator of stress built up on faults

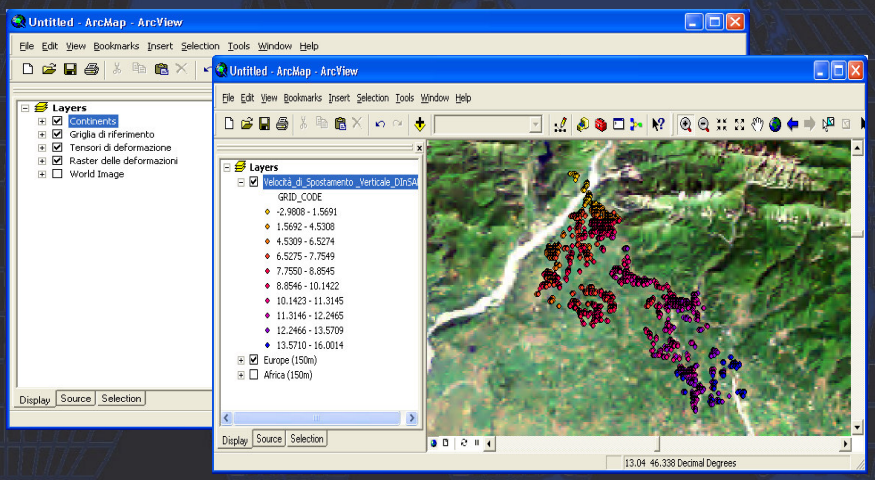
Umbria-Marche → post-seismic phase

Where possible phenomena (e.g. afterslip, post-seismic relaxation) may affect the stress field in the lithosphere.

SISMA: system engineering requirements

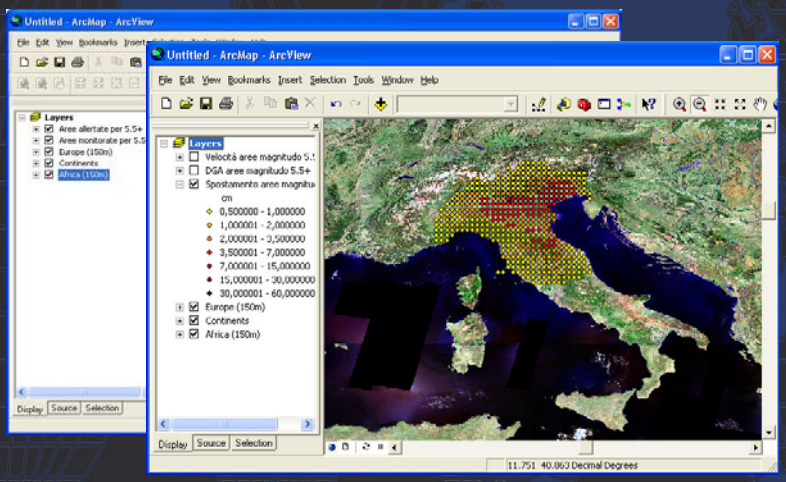
- Procedures for **verification** and **validation** of applied methodologies
- Unit and Integration tests for developed software
- Validation tests for developed products
- Formal definition of interfaces
- **Automatic software documentation** (Robodoc)
- **Revision control system** (Subversion) **applied to software, documents and products**

SISMA: products GIS interface



DInSAR Displacements (V2)

SISMA: products GIS interface



Regional Bedrock Ground Shaking (V1)

Conclusions

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

Conclusions

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