The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

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"Workshop on the Conduct of Seismic Hazard Analyses
for Critical Facilities"

15 - 19 May 2006

Deterministic Methods in Seismic Hazard Analysis

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Deterministic methods in seismic hazard analysis

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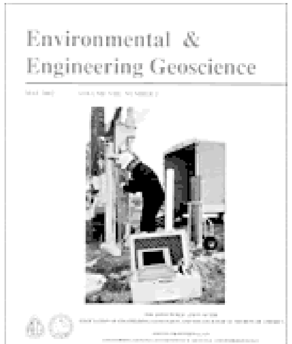
DST - Universita’ di Trieste
and
SAND Group - the Abdus Salam International Centre for Theoretical Physics

15 May 2006

GENERAL PROBLEMS IN SEISMIC HAZARD ASSESSMENT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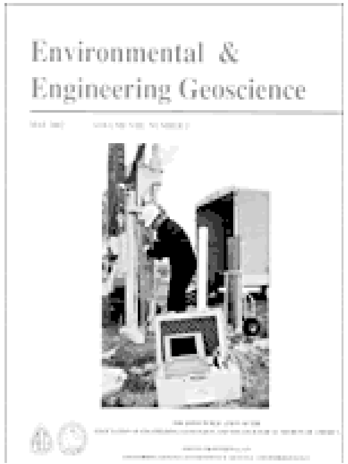
Nov 1998, 4, 425-443

The hazard in using probabilistic seismic hazard analysis for engineering

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

Both the deterministic and probabilistic methods of seismic hazard analysis serve necessary purposes. Probability is needed to obtain operating basis earthquakes, to perform risk analyses, to prioritize projects, and for assigning recurrence estimates to deterministic earthquakes. The probability for these purposes is used as a relativistic measure. The problem with seismic probability is that it relies on the Gutenberg-Richter b-line, which has severe shortcomings. There are corrections that can be applied, which attempt to remedy the problems. Data are introduced for paleoseismic events, characteristic earthquakes, and slip-rate, or judgments are introduced from logic trees, multiple expert opinions, etc. Unfortunately, none are equal to the task. The probabilistic seismic hazard analyses remain fundamentally limited in their dependability. However, the deterministic method can provide evaluations that are at a practical level for engineering. Engineering design must be done deterministically if one is to have seismic safety coupled with good engineering judgement. The design for critical structures, those for which failure is intolerable, such as dams, nuclear power plants, hazardous waste repositories, etc., must be based on maximum credible earthquakes, obtained by deterministic procedures, in order to assure their seismic safety.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ENGINEERING GEOLOGY

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Opinion paper

PSHA: is it science?

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Accepted 18 February 2002

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. © 2002 Elsevier Science B.V. All rights reserved.

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

Introduction

- Case studies of seismic hazard assessment indicate the limits of the currently used methodologies, deeply rooted in engineering practice, based on a probabilistic approach. The probabilistic analysis supplies indications that can be useful but are not sufficiently reliable to characterize the seismic hazard.

WHY?

The Gutenberg-Richter magnitude-frequency relationship

Log N=a-bM

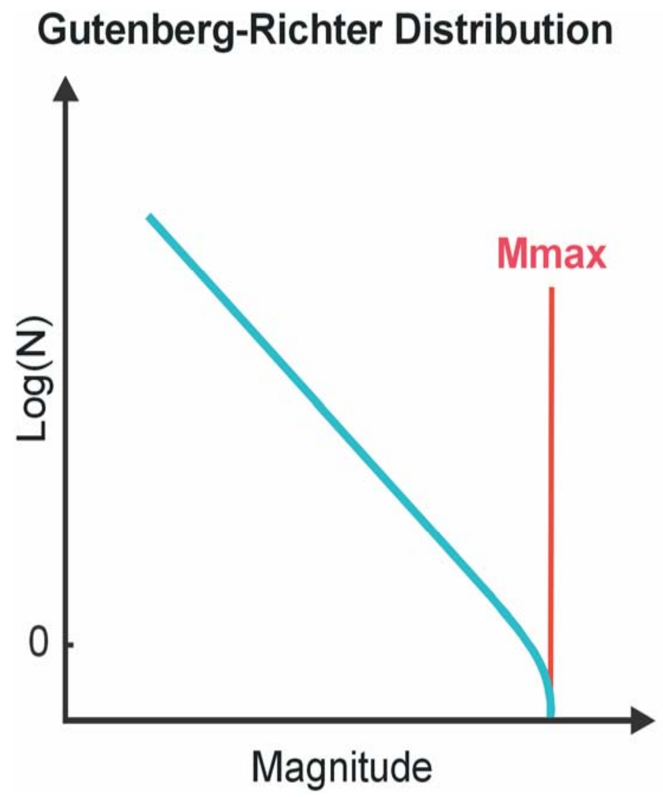
is the most commonly cited example of naturally occurring SOC phenomena.

- Accordingly to the **multiscale seismicity model** (Molchan et al., 1997) only the ensemble of events that are geometrically small, compared with the elements of the seismotectonic regionalization, can be described by a log-linear frequency-magnitude (FM) relation.

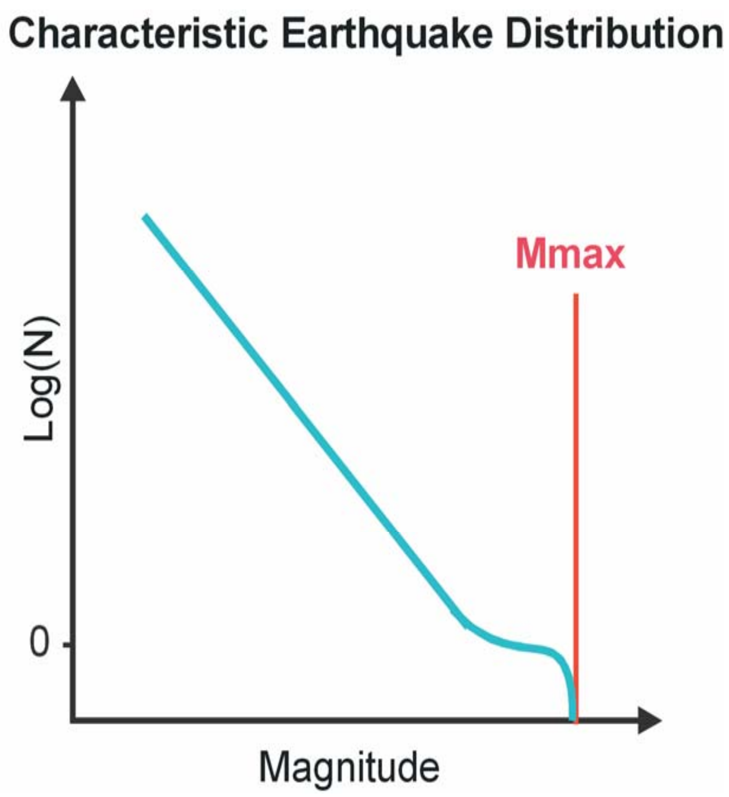
- This condition, largely fulfilled by the early global investigation by Gutenberg and Richter, has been subsequently violated in many investigations.
- This violation has given rise to the Characteristic Earthquake (CE) concept in opposition to the Self-Organized Criticality (SOC) paradigm.

Multiscale seismicity model

Self-Organized Criticality
(SOC) model



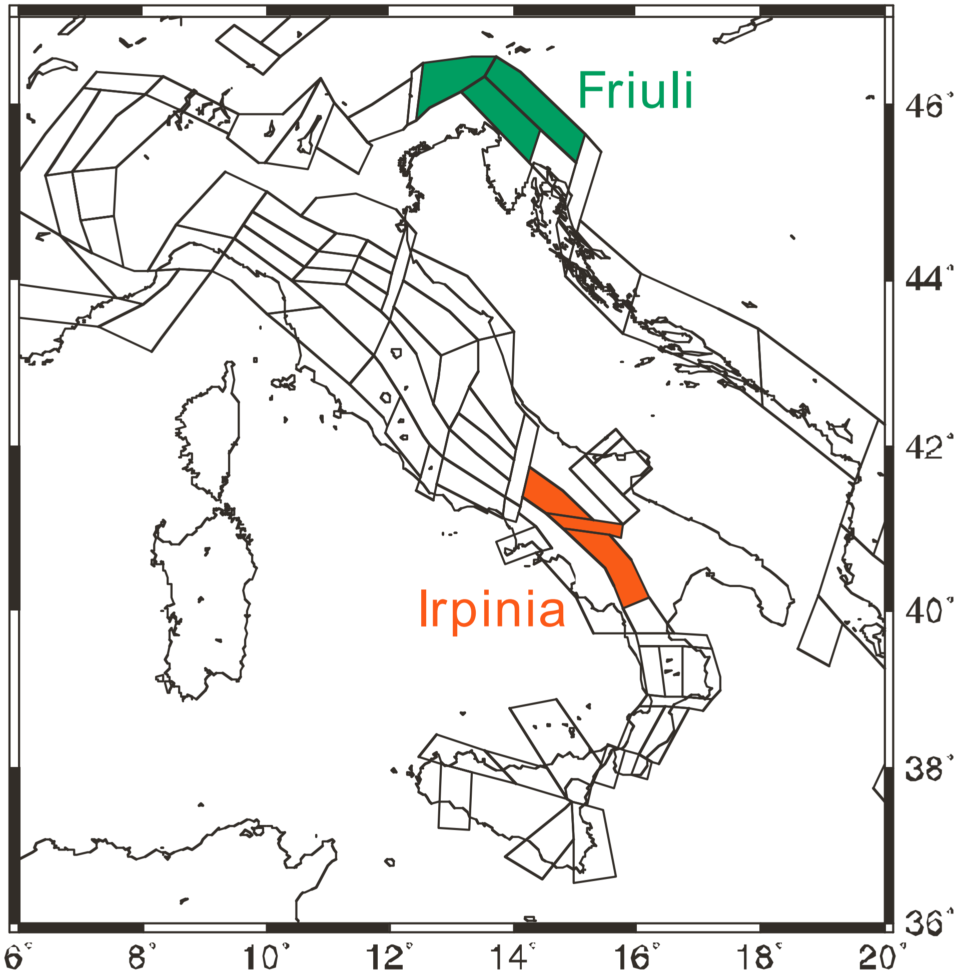
Characteristic Earthquake
(CE) model



CUMULATIVE

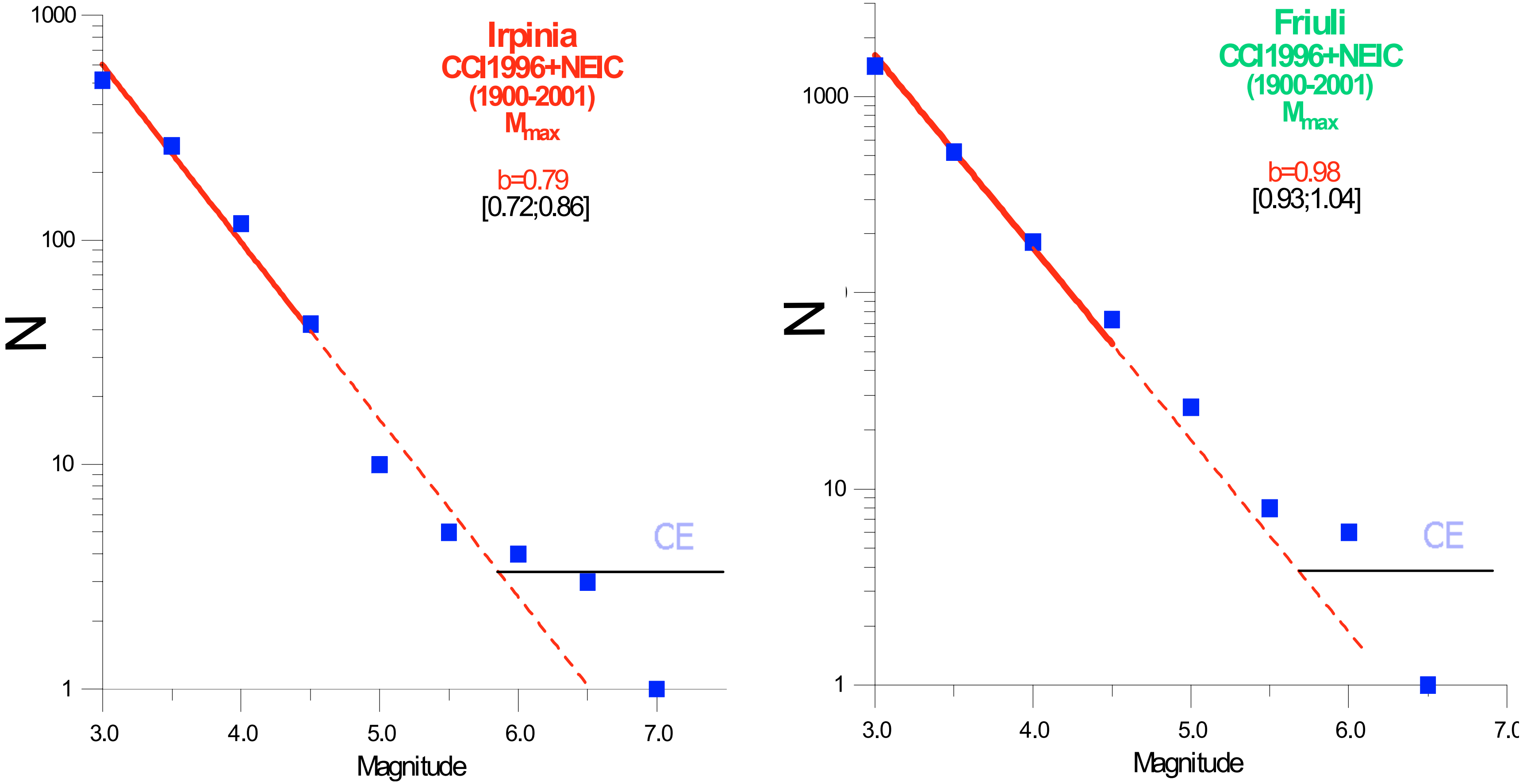
EXAMPLES of the appearance of SOC and CE properties depending opon the size of the area considered.

Gutenberg-Richter law

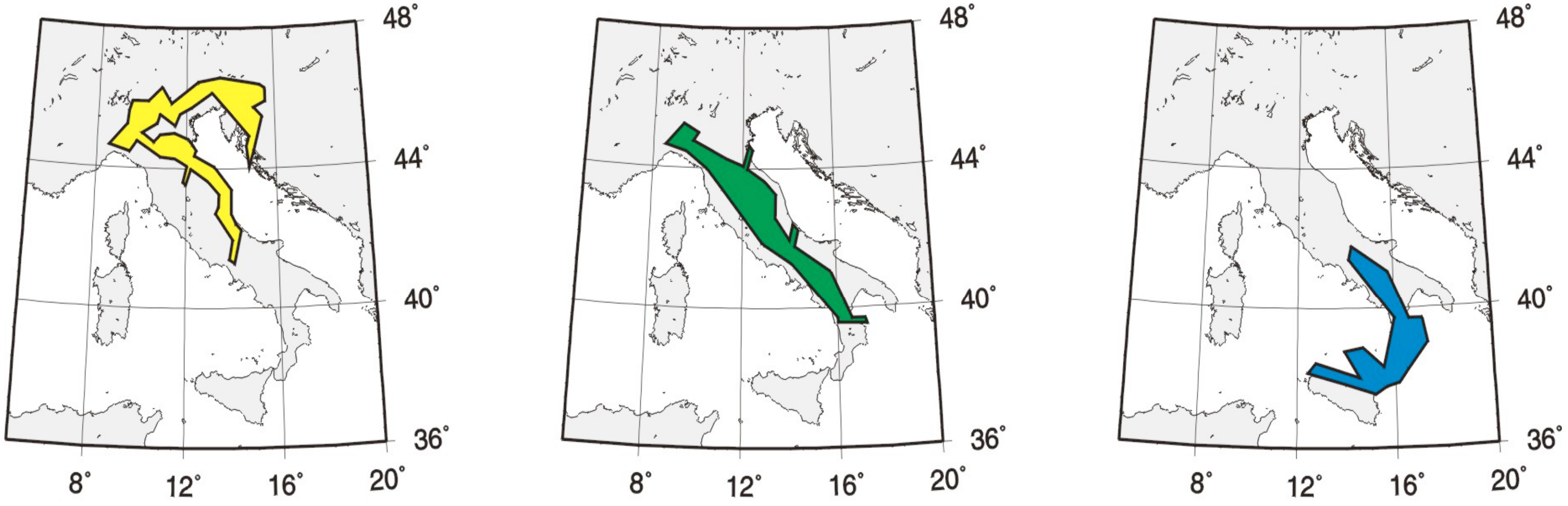


Union of GNDT zones used for the definition of zones of level 1. We show the examples of the Friuli (1976) and Irpinia (1980) quakes. The union is given by the GNDT zones where aftershocks have been recorded.

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



(cumulative distribution)

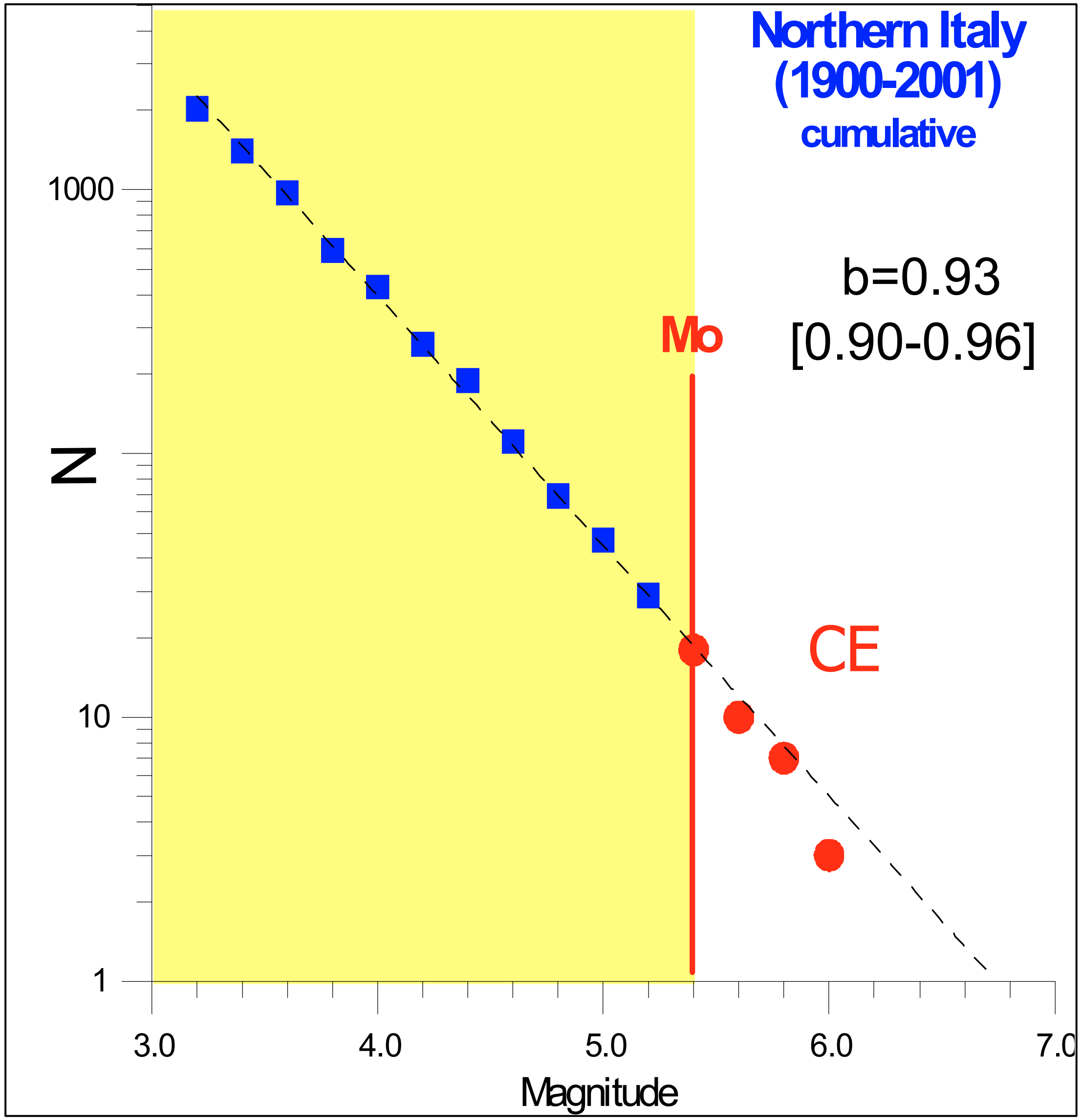


Northern Region: M_0=5.4

Central Region: M_0=5.6

Southern Region: M_0=5.6

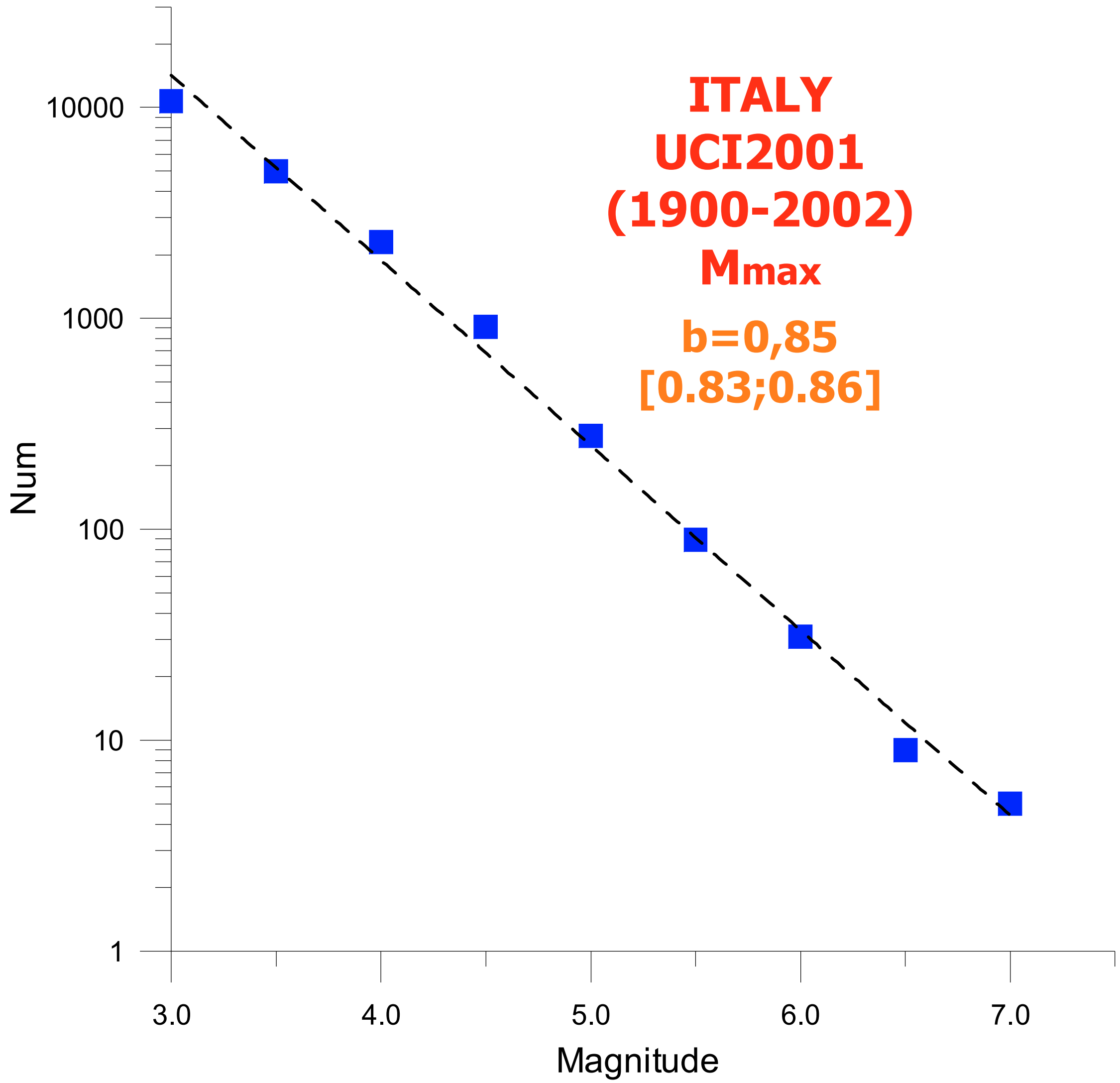
Union of GNDT zones used for the definition of zones used to apply CN algorithm



(cumulative distribution)

The Gutenberg Richter law when applied to large (about 500 km in length) parts of Italy is linear over the magnitude interval [3-5.4].

Multiscale seismicity model



The GR law for the whole Italian territory is linear in the magnitude interval (3-7)

All events

Non-Cumulative

Thus the extension (size) of the study area controls the range of Magnitude in which the log-linear GR law is applicable. This has obvious consequences on PSHA.

Another way of stating this is the introduction of the following unified scaling law (Kossobokov and Mazhkenov, 1994)

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

Where N(M,L) is the expected annual number of earthquakes at a seismically active site of linear dimension L.

The observed temporal variability of A, B, C indicates significant changes of seismic activity, and, therefore, implies using all the data available for a long-term seismic hazard assessment, as well as regional monitoring of these characteristics for evaluation of time-dependent risk in real-time.

? GSHAP ?

Kobe (17.1.1995), Gujarat (26.1.2001), Boumerdes (21.5.2003) and Bam (26.12.2003) earthquakes

	PGA(g)	
	Expected with probability of excedance 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

*from I; if possible liquefaction phenomena are considered, the observed value can be even smaller.

A problem connected with GSHAP probabilistic maps, due to the improper use of macroseismic Intensity.

Numerous empirical relations (see Shteinberg et al., 1993 and references therein) between maximum macroseismic intensity, I (MCS), and logPGA have a slope close to 0.3, in agreement with the early modification introduced in the Mercalli scale by Cancani (1904).

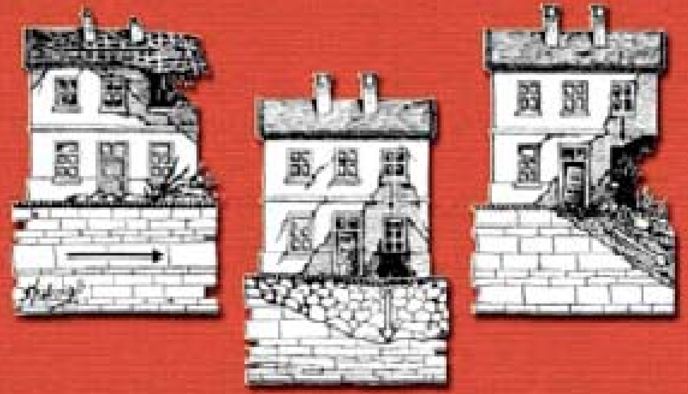
ОПИТИ И ПОУКИ ВЪРХУ ПРОИЗХОДА, ПРЕДПАЗВАНЕТО И ОТСТРАНЯВАНЕТО НА ПОВРЕДИТЕ ОТ ЗЕМЕТРЕСЕНИЯТА / А. ЗИБЕРГ
EXPERIENCES AND LESSONS ON THE ORIGIN, PREVENTION AND ELIMINATION OF EARTHQUAKE DAMAGES / A. SIEBERG

А. Зиберг

ОПИТИ И ПОУКИ ВЪРХУ ПРОИЗХОДА, ПРЕДПАЗВАНЕТО И ОТСТРАНЯВАНЕТО НА ПОВРЕДИТЕ ОТ ЗЕМЕТРЕСЕНИЯТА

A. Sieberg

EXPERIENCE AND LESSONS ON THE ORIGIN, PREVENTION AND ELIMINATION OF EARTHQUAKE DAMAGES



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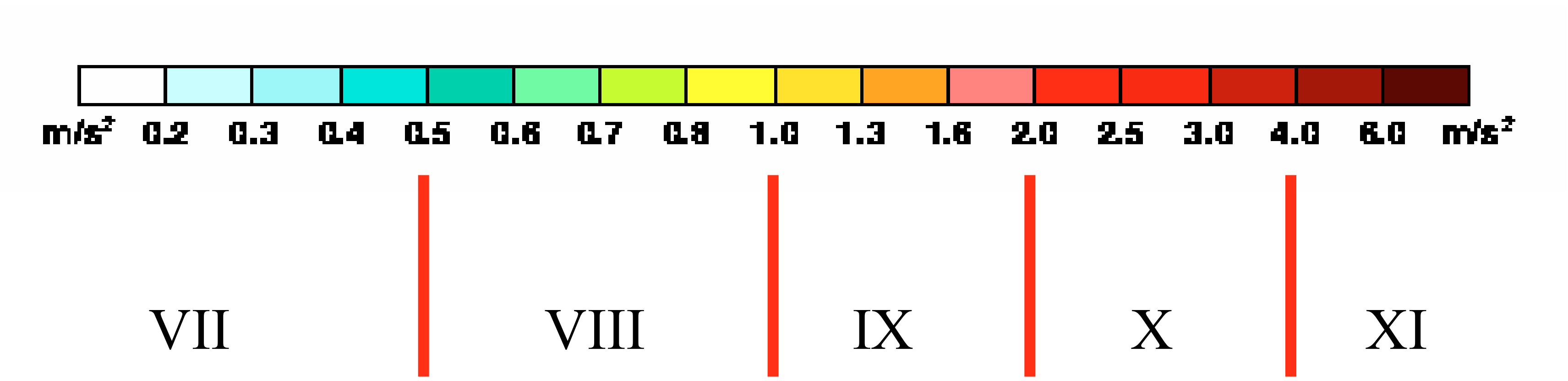
```
DGA(I)/DGA(I-1)=2

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

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

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



? GSHAP ?

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

Realistic ground motion modelling

A proper definition of the seismic input at a given site can be done following **two main approaches**.

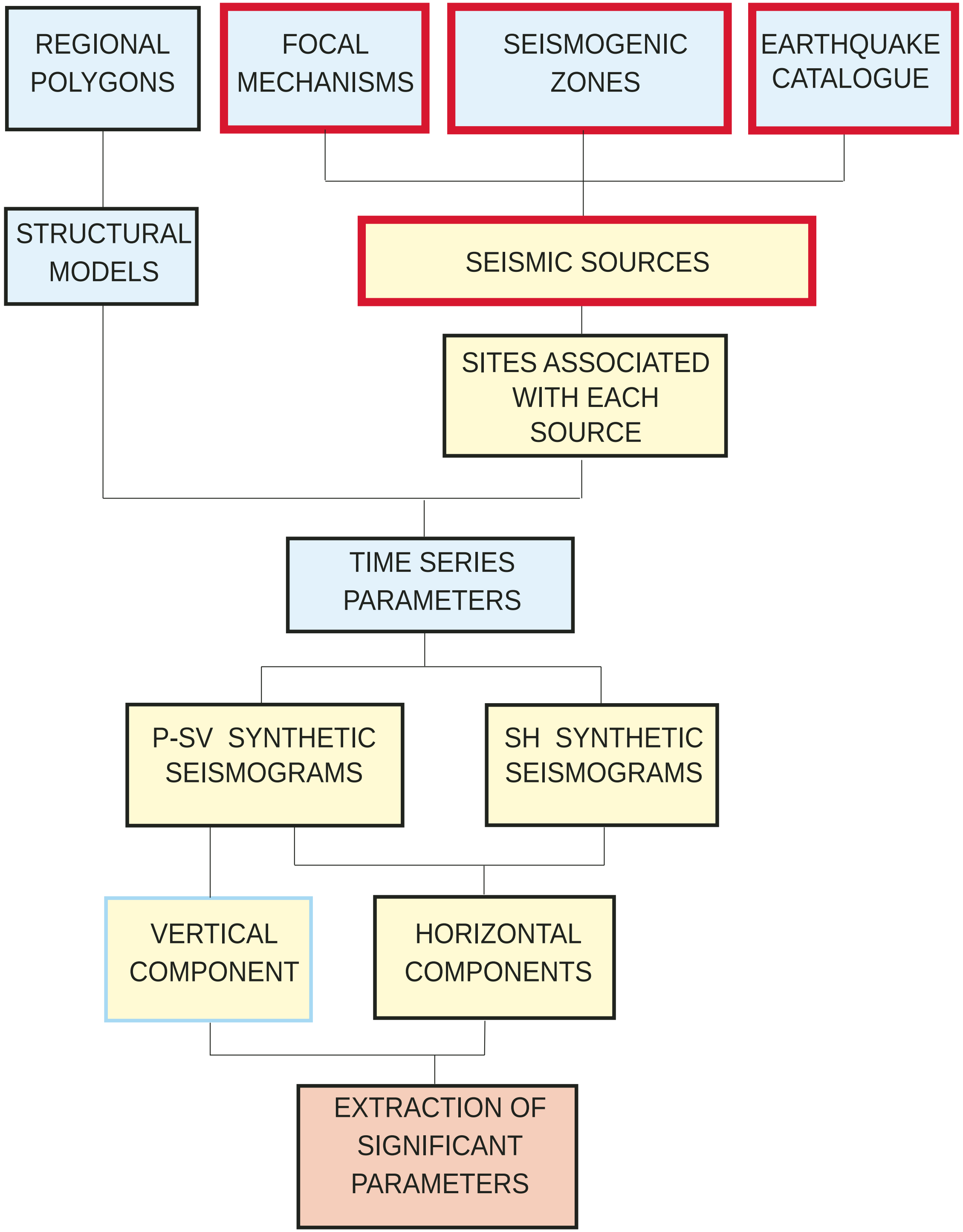
The first approach is based on the analysis of the available strong motion databases, collected by existing seismic networks, and on the grouping of those accelerograms that contain similar source, path and site effects (*e.g. Decanini and Mollaioli, 1998*).

The second approach is based on modelling techniques, developed from the knowledge of the seismic source process and of the propagation of seismic waves, that can realistically simulate the ground motion (*Panza et al., 1996; Field et al., 2000*).

The ideal procedure is to follow the two complementary ways, in order to validate the numerical modelling with the available recordings (*e.g. Decanini et al., 1999; Panza et al., 2000a,b,c*).

Our innovative 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**.

Flow-chart of the method



REGIONAL POLYGONS

FOCAL MECHANISMS

SEISMOGENIC ZONES

EARTHQUAKE CATALOGUE

STRUCTURAL MODELS

SEISMIC SOURCES

SITES ASSOCIATED WITH EACH SOURCE

TIME SERIES PARAMETERS

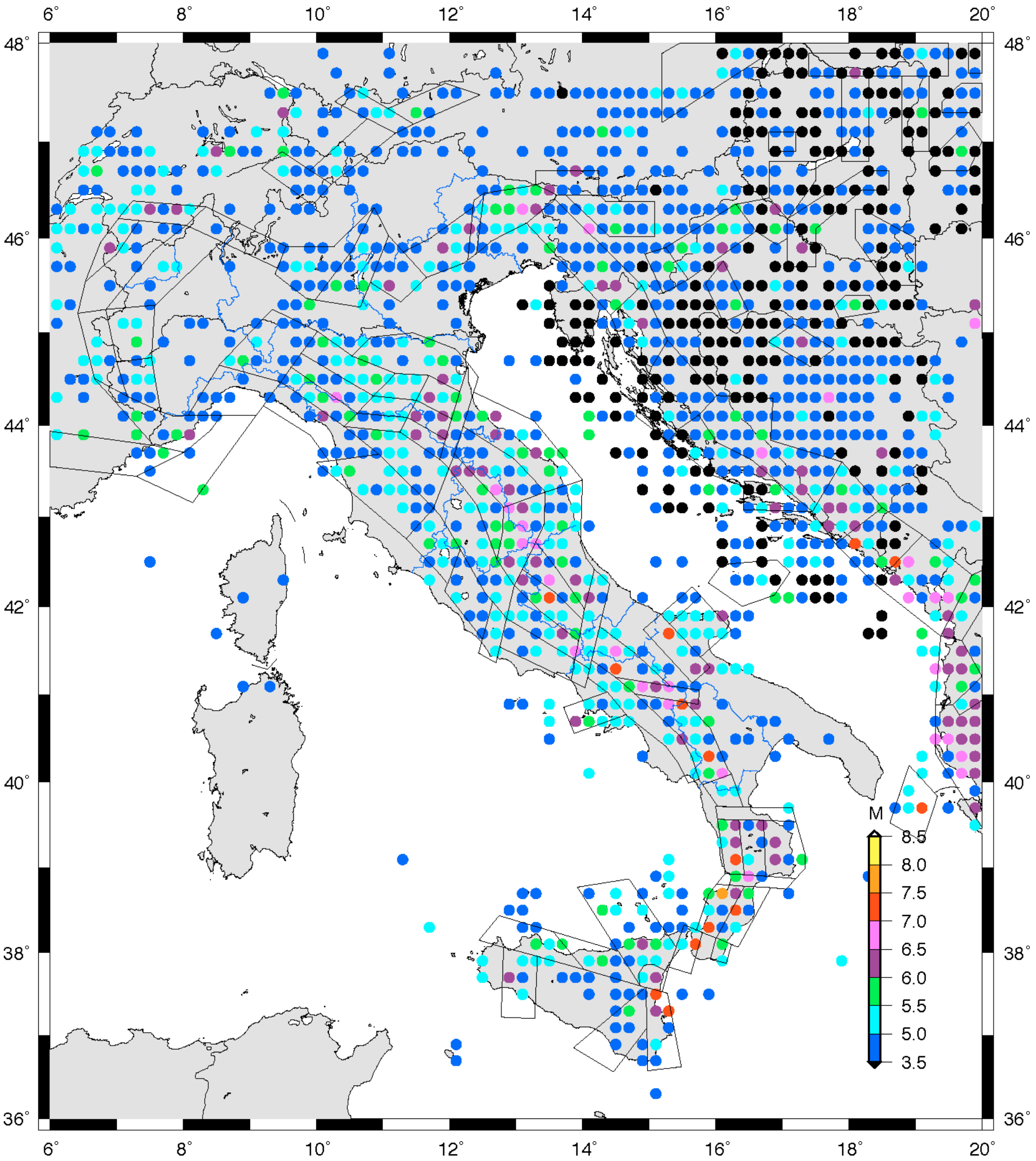
P-SV SYNTHETIC SEISMOGRAMS

SH SYNTHETIC SEISMOGRAMS

VERTICAL COMPONENT

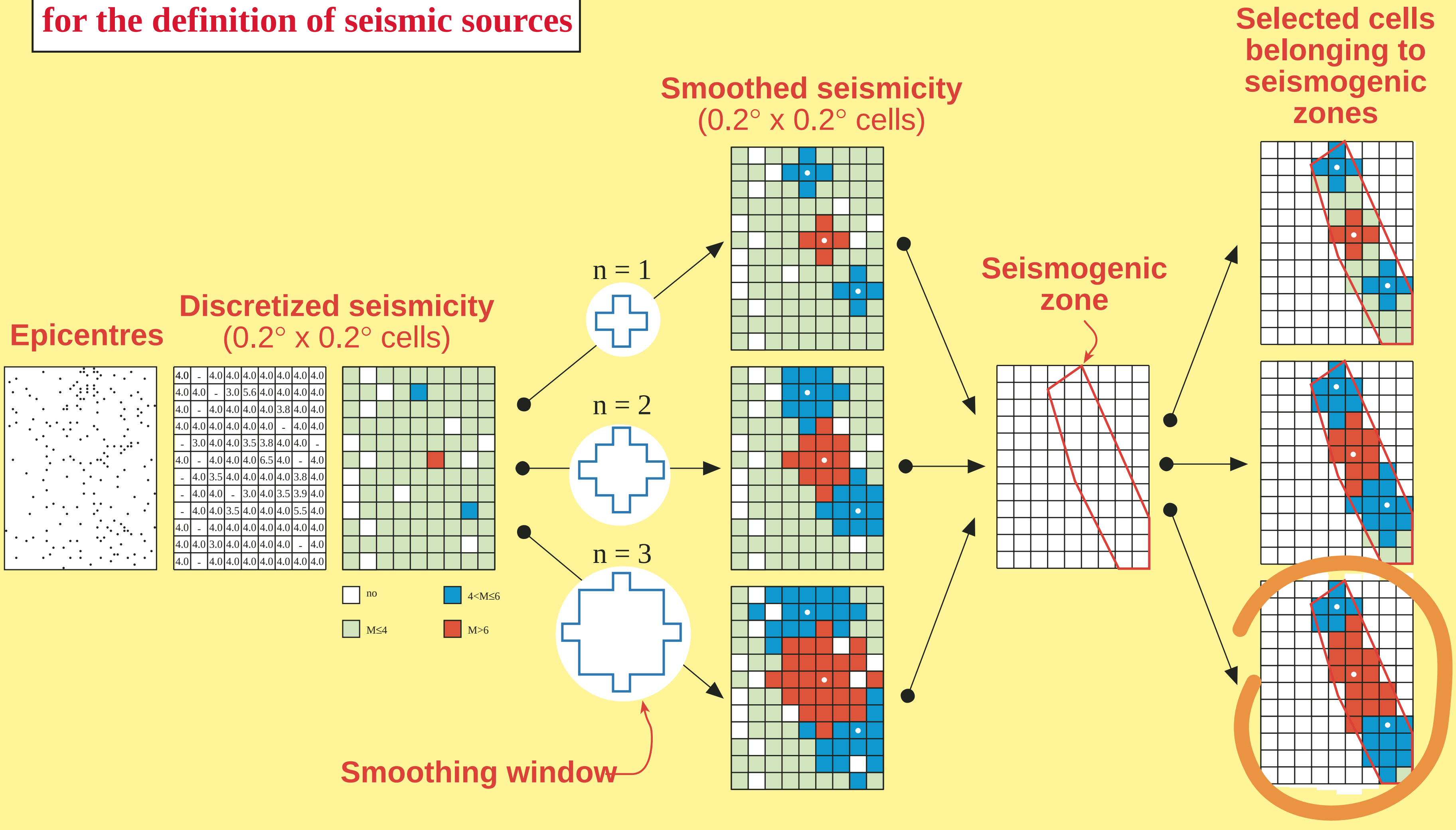
HORIZONTAL COMPONENTS

EXTRACTION OF SIGNIFICANT PARAMETERS



Observed maximum magnitude in the period 1000-1992 (symbols), and seismotectonic model (poligons)

SMOOTHING OF SEISMICITY
for the definition of seismic sources



Epicentres

Discretized seismicity
(0.2° x 0.2° cells)

4.0	-	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.0	4.0	-	3.0	5.6	4.0	4.0	4.0	4.0
4.0	-	4.0	4.0	4.0	4.0	3.8	4.0	4.0
4.0	4.0	4.0	4.0	4.0	4.0	-	4.0	4.0
-	3.0	4.0	4.0	3.5	3.8	4.0	4.0	-
4.0	-	4.0	4.0	4.0	6.5	4.0	-	4.0
-	4.0	3.5	4.0	4.0	4.0	4.0	3.8	4.0
-	4.0	4.0	-	3.0	4.0	3.5	3.9	4.0
-	4.0	4.0	3.5	4.0	4.0	4.0	5.5	4.0
4.0	-	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.0	4.0	3.0	4.0	4.0	4.0	4.0	-	4.0
4.0	-	4.0	4.0	4.0	4.0	4.0	4.0	4.0

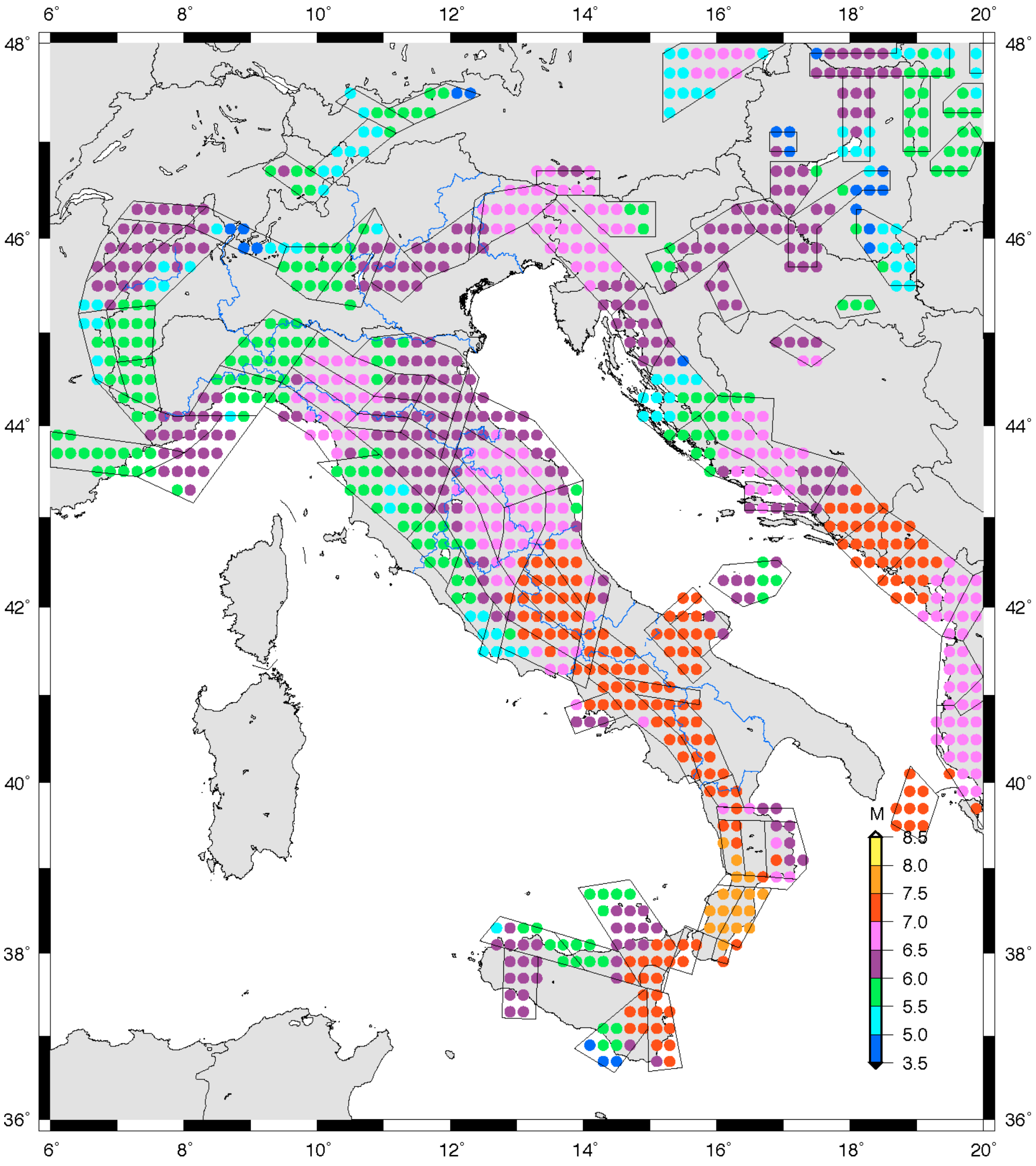
Smoothing window

Smoothed seismicity
(0.2° x 0.2° cells)

Seismogenic zone

Selected cells belonging to seismogenic zones

n=3 is our choice



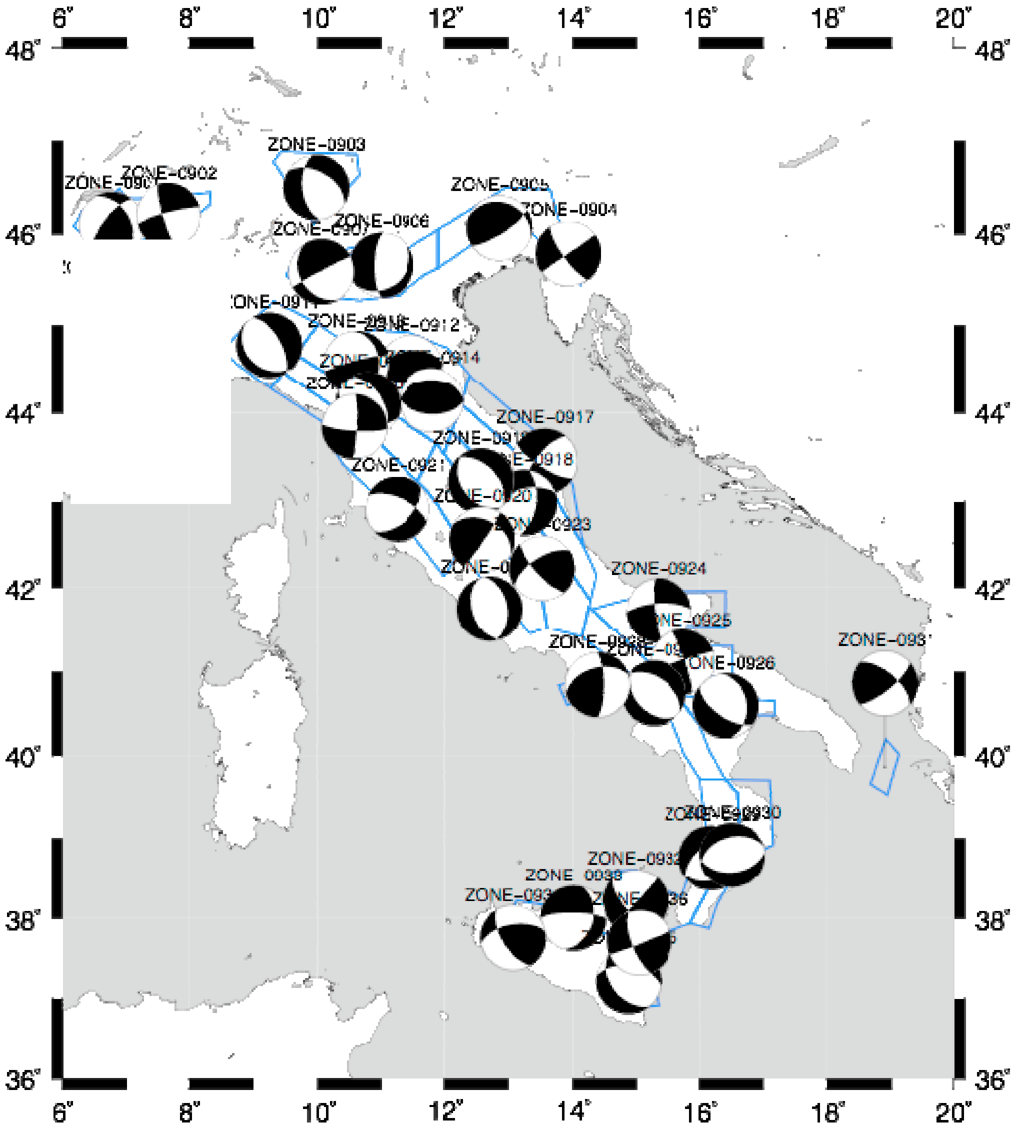
Magnitude smoothed within the seismotectonic zones

Regional Scale - Definition of Sources

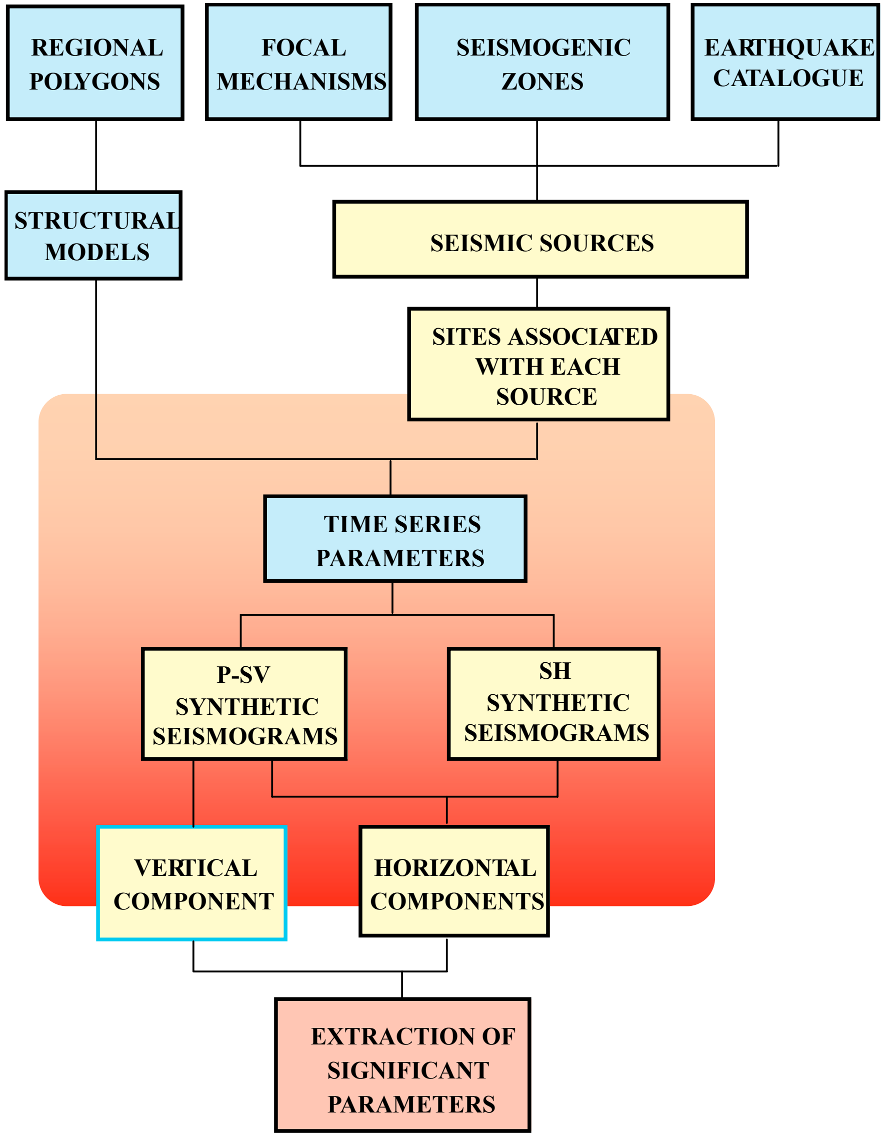
FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude



Regional Scale - Displacements



REGIONAL POLYGONS

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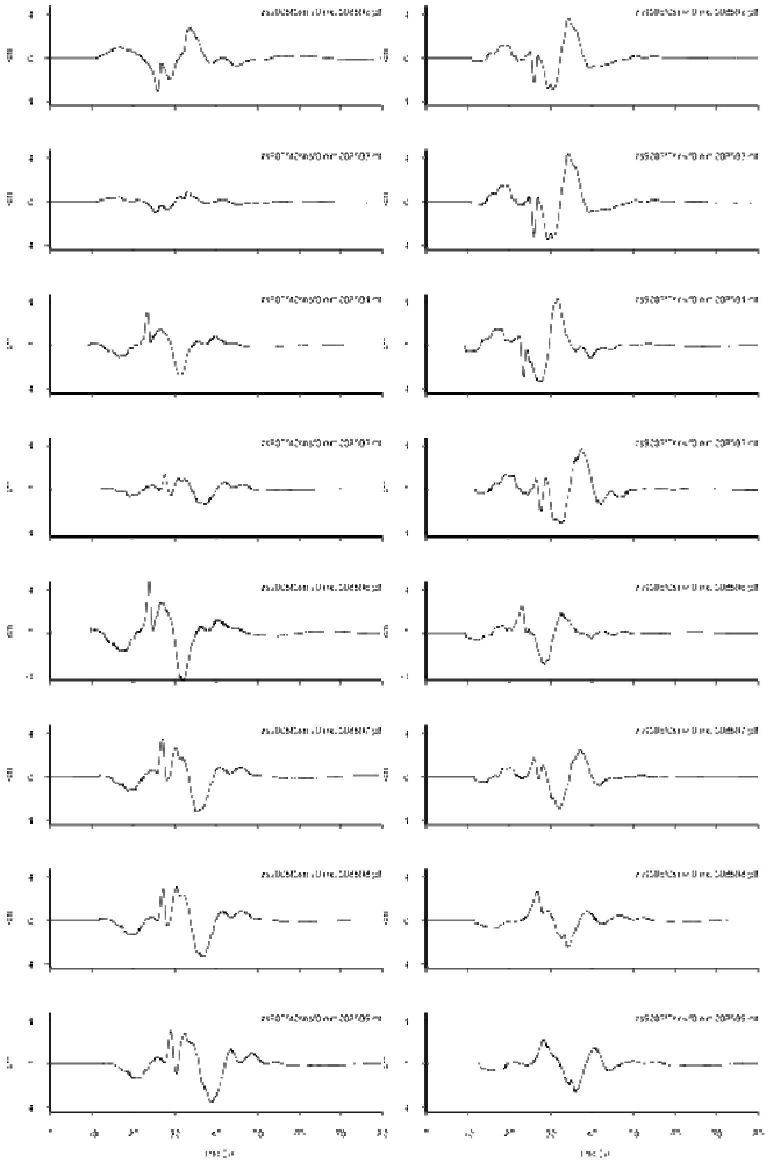
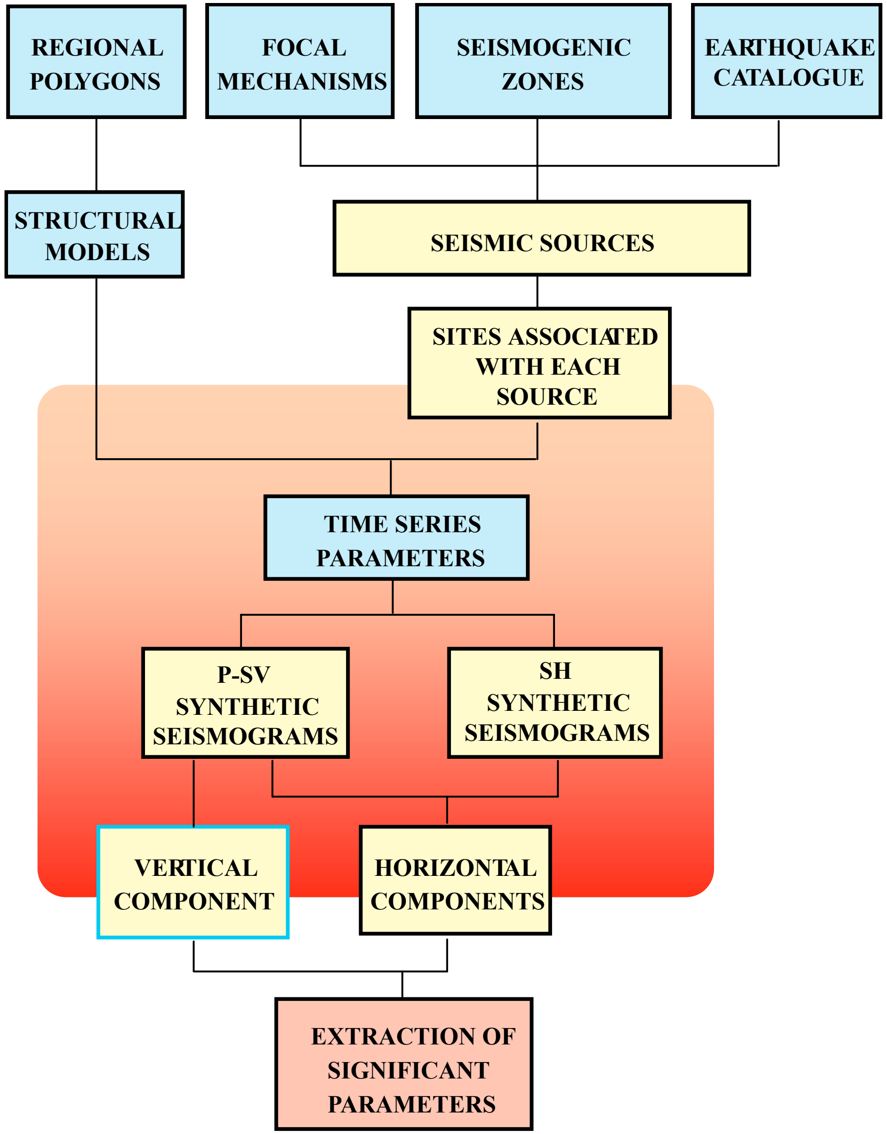


Regional Scale - Velocities



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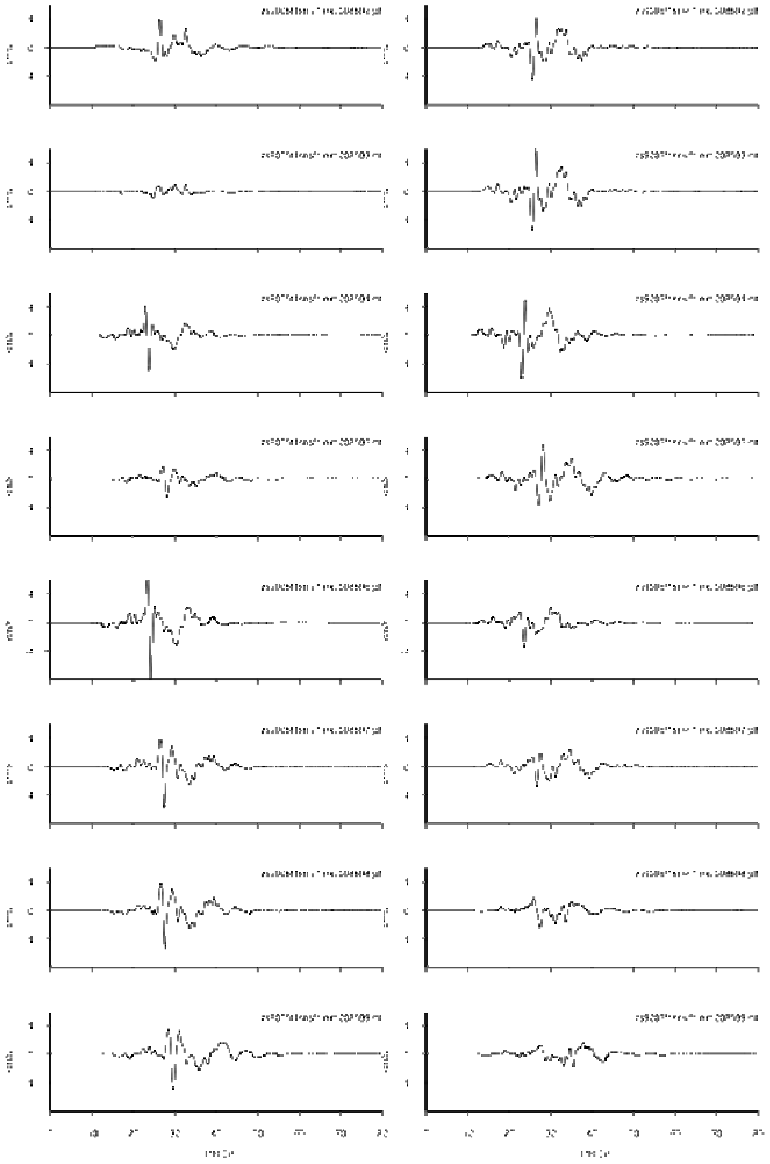
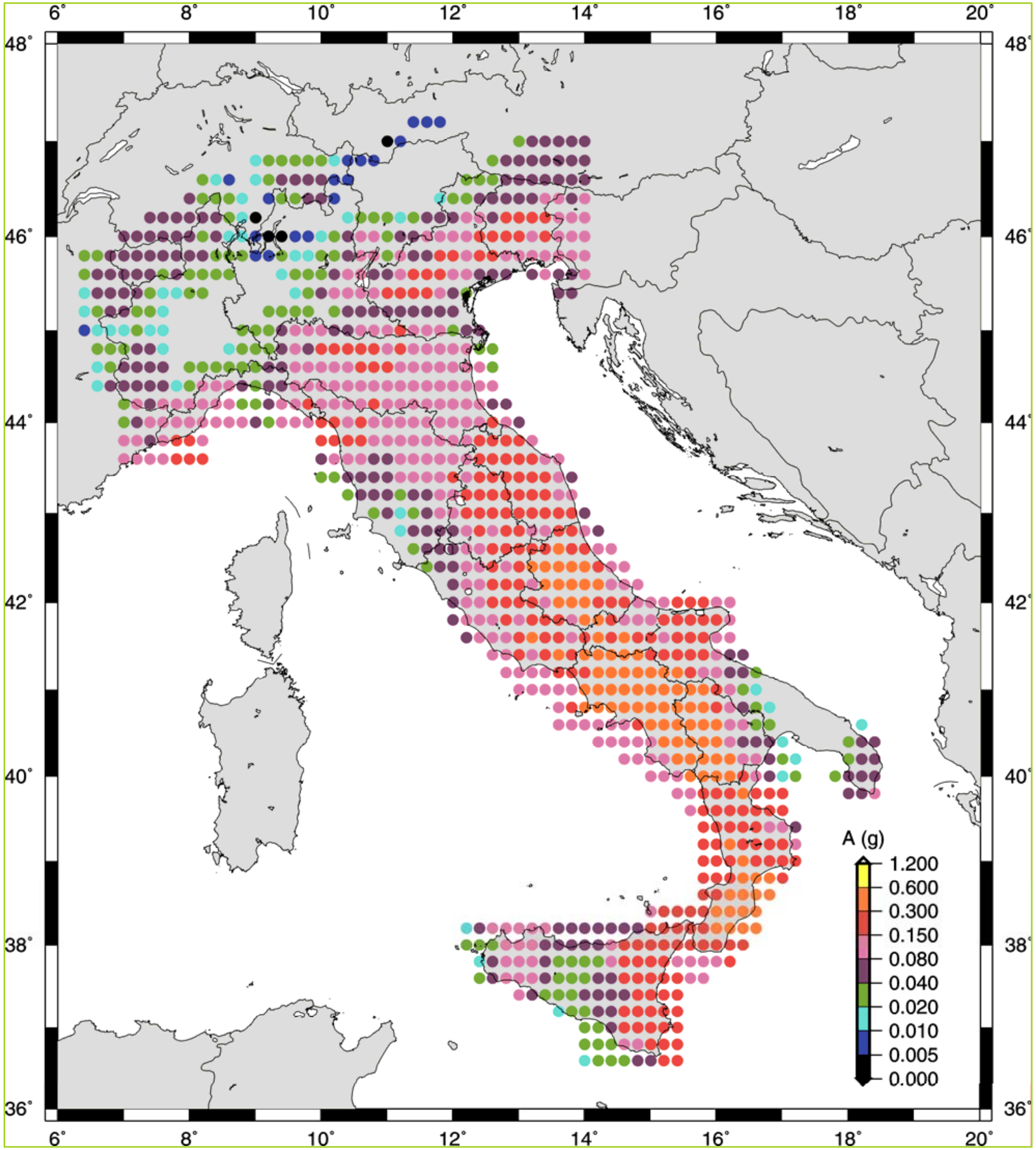
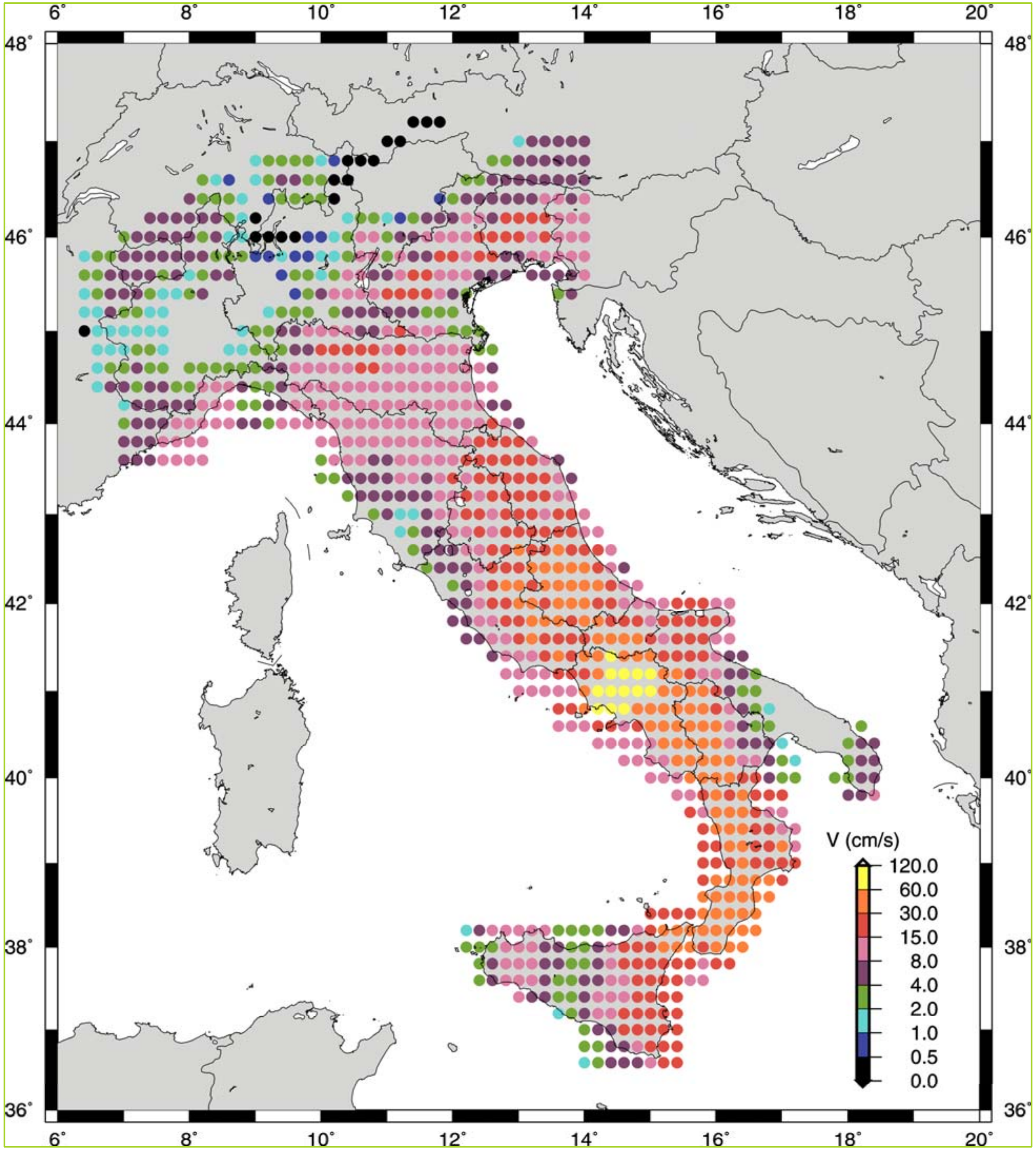




DGA=EPA

Maximum estimated Design Ground Acceleration, consistent with Eurocode 8

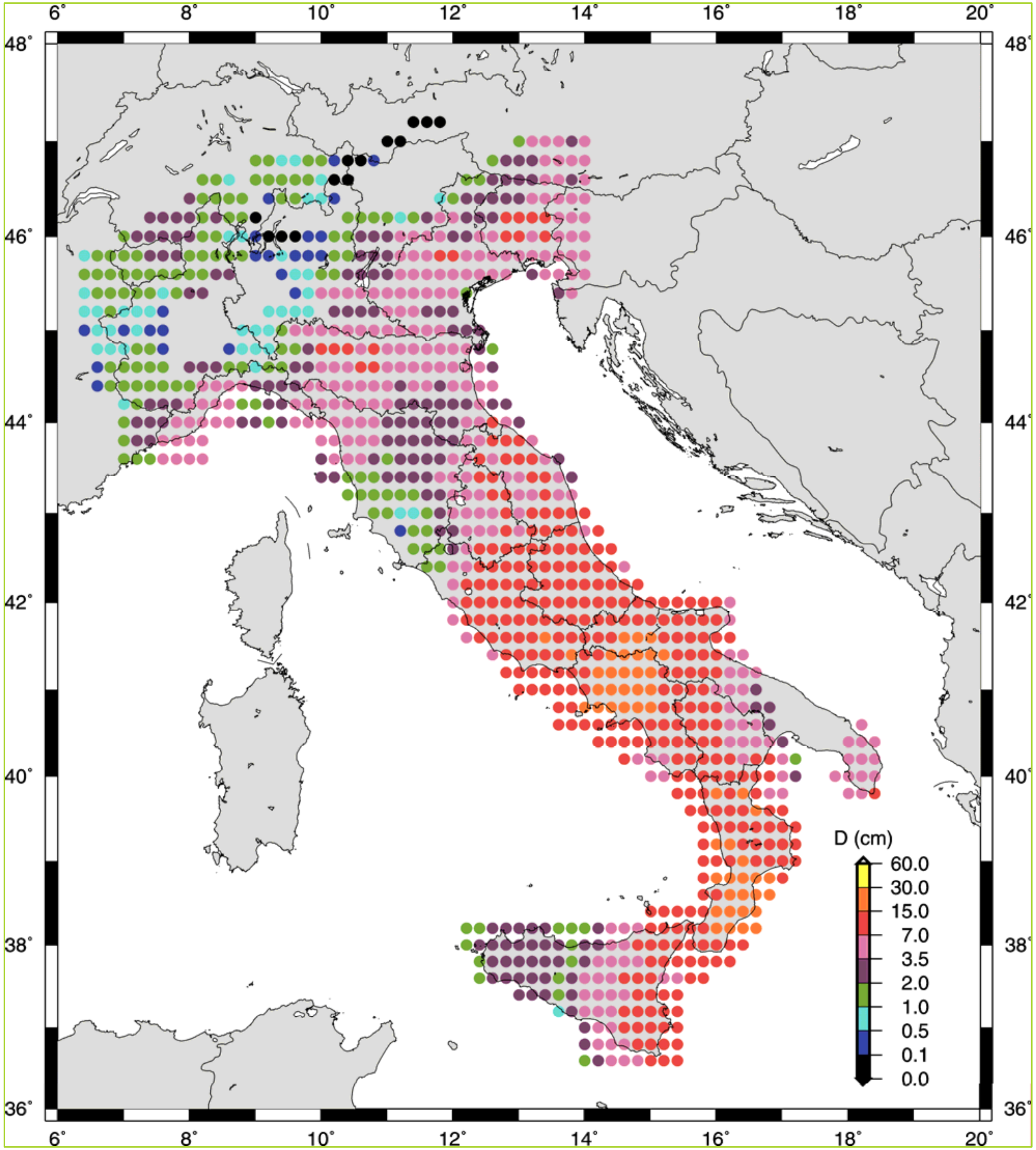
Deterministic Method



PGV

Maximum estimated velocity

Deterministic Method



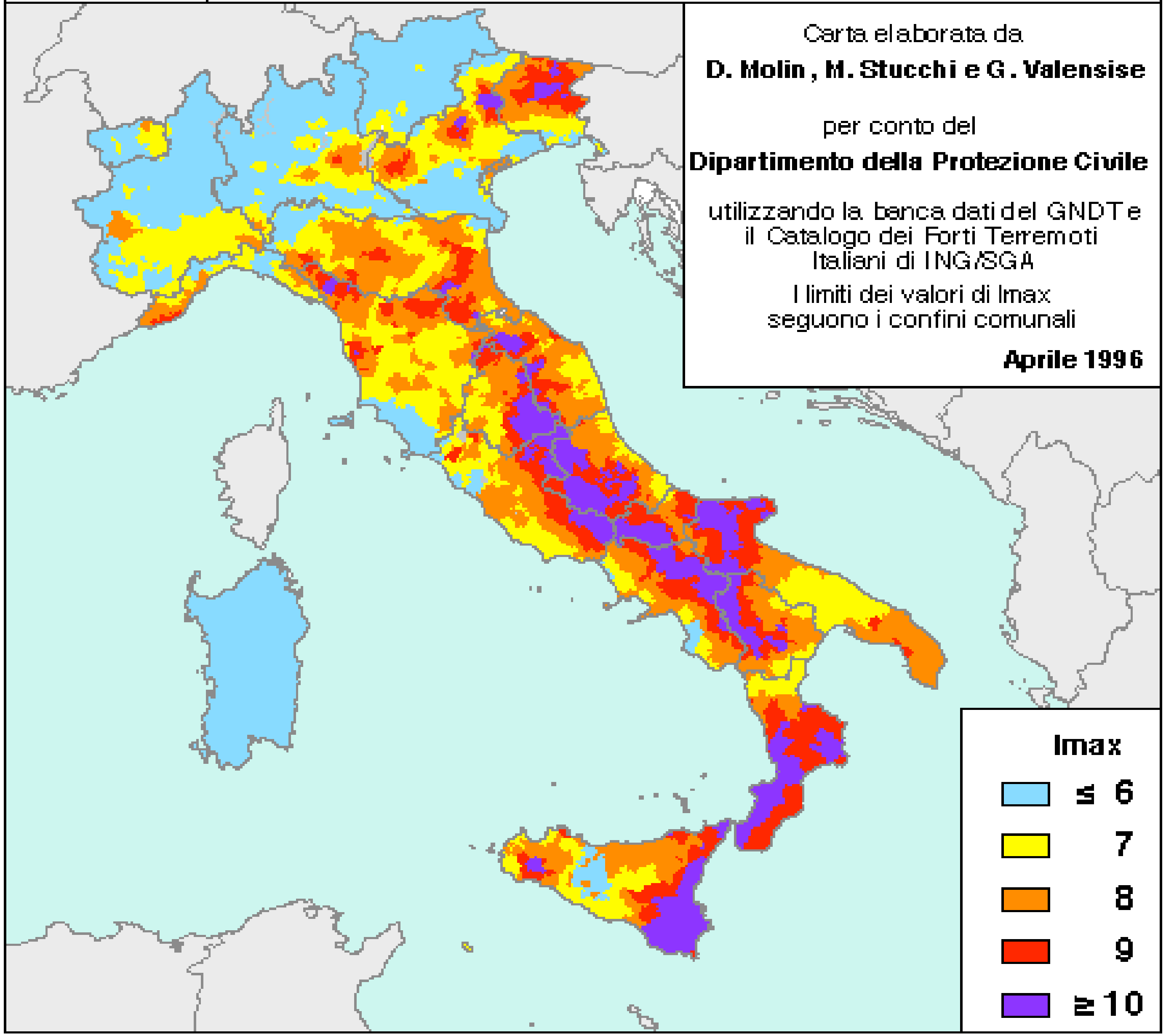
PGD

Maximum estimated displacement, particularly relevant for seismic isolation

Deterministic Method

GNDT
ING
SSN

Massime intensità macrosismiche osservate nei comuni italiani



Carta elaborata da
D. Molin, M. Stucchi e G. Valensise

per conto del
Dipartimento della Protezione Civile

utilizzando la banca dati del GNDT e
il Catalogo dei Forti Terremoti
Italiani di ING/SGA
I limiti dei valori di Imax
seguono i confini comunali

Aprile 1996

The regression between maximum macroseismic intensity, I (MCS), and computed ground motion peak values (Panza et al., 1999) has a slope close to 0.3 in agreement with the early modification introduced in the Mercalli scale by Cancani (1904).

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

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

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

The deterministic zonation gives peak values well in agreement with effective values recorded (~ 0.3g) during the 1997 Umbria-Marche sequence.

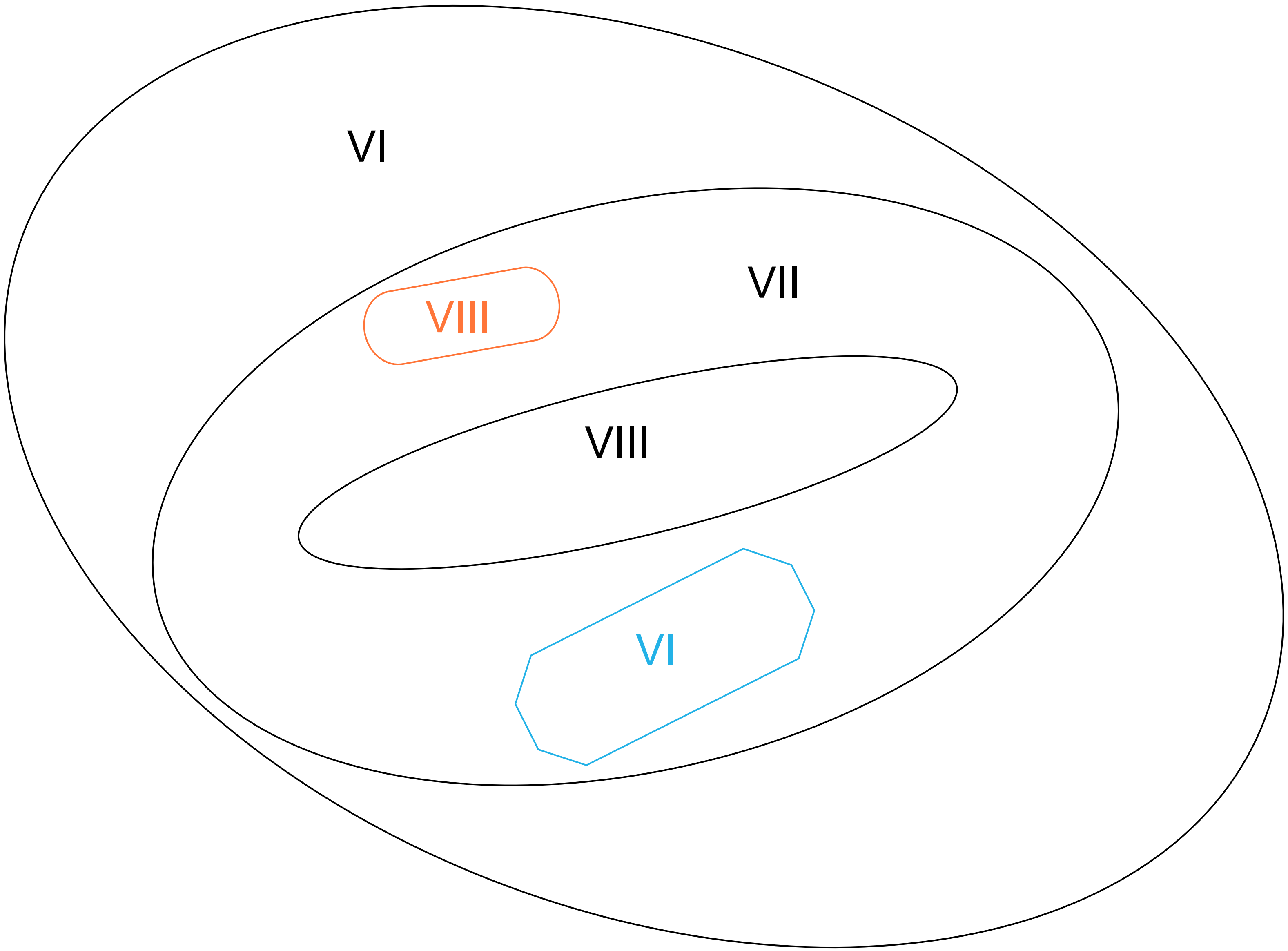
The Molise earthquake of 31 October 2002 reached a MCS intensity of at least VIII. The deterministic map indicates ground motion peak values well in agreement with intensity IX.

Effects of local soil conditions

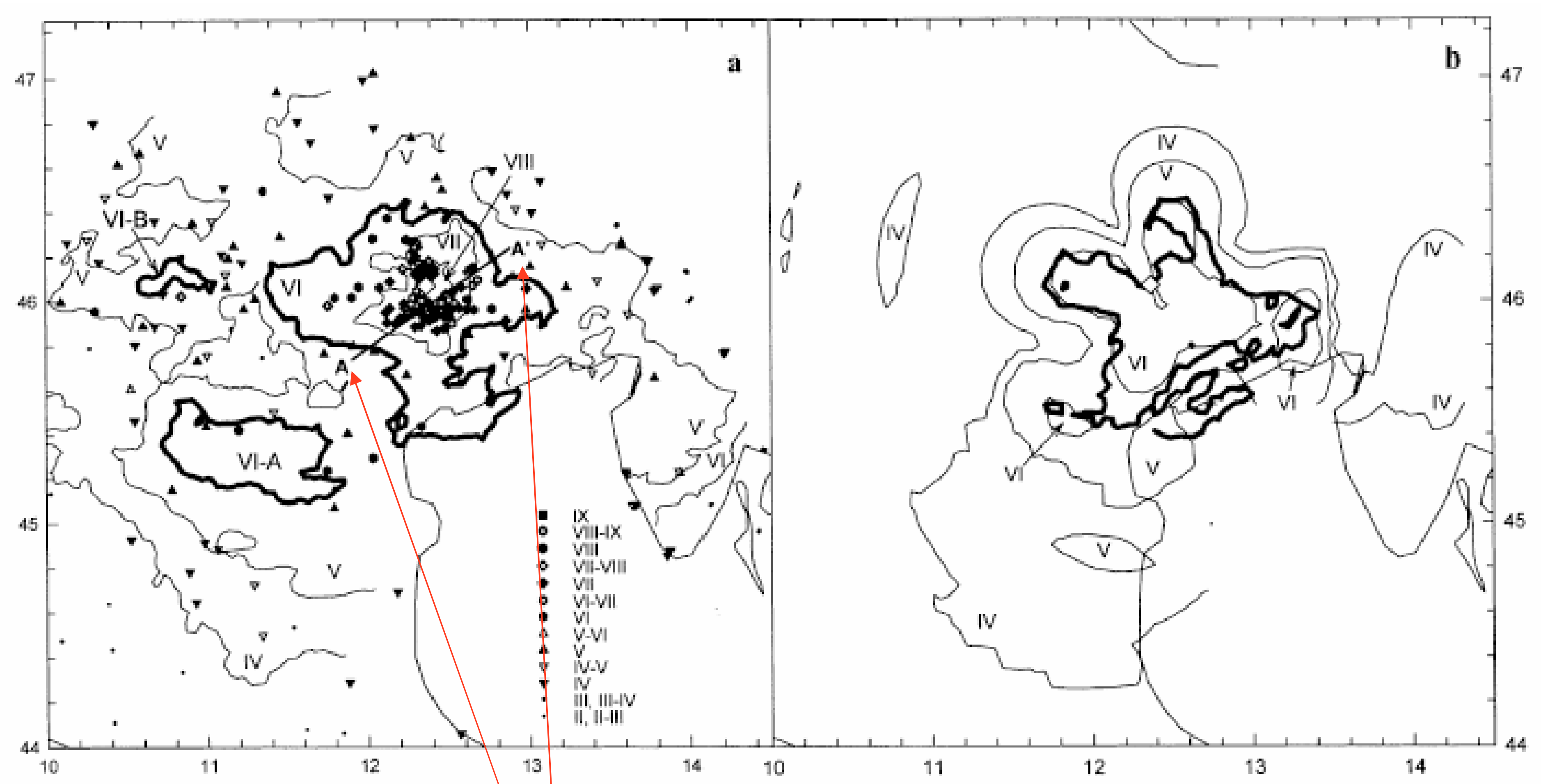
Isoseismals shape

Isoseismals shape

- Particularly important for engineering purposes, we show examples of the perspectives offered by the analysis of the multi-connected isoseismals to reveal site effects.
- The database of MS data like the one available for Italy, the synthetic isoseismal modeling and the technique we developed provide a good basis for a systematic analysis of the relation between MS data and source geometry.

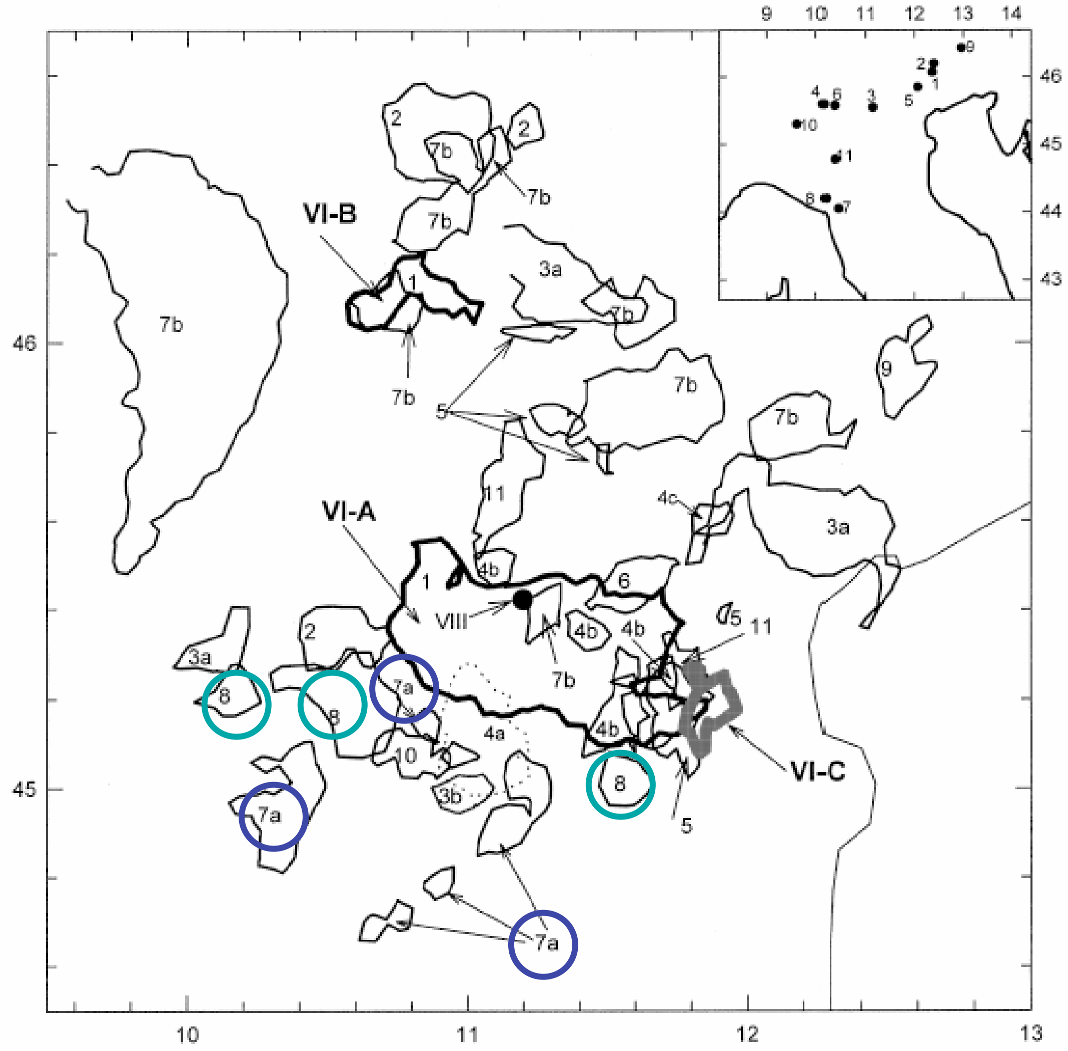


Schematic representation of multi-connected isoseismals



Alpago earthquake (18.10.1936, M_L=5.8): MCS Intensity data (*point-like symbols*) and isolines defined with polinomial filtering; segment (A, A') separates the zone with $I \geq$VI on mountain from that on plain. Areas VI-A e VI-B are local effects?

(b) isolines of the synthetic a_p-field (*thin line*) and reconstruction of the theoretical I_a=VI isoline (*bold line*) using the original observation points and the polynomial filtering technique (Molchan et al., 2002, PAGEOPH, 159).



1) 18.10.1936, Alpago, V+1 (*think line*; VI-A, VI-B), area VI-C is an alternative to the area VI-A due to instability of the the polynomial.

2) 29.06.1873, Bellunese, V+1 (2).

3) 7.06.1891, Veronese, IV+1 (3a), V+1 (3b).

4) 27.11.1894, Franciacorta, IV-1 (4a, *dotted line*), III+1 (4b), II+1 (4c).

5) 4.03.1900, Valdobbiadene, IV+1 (5).

6) 30.10.1901, Salo, IV+1 (6).

7) 27.10.1914, Garfagnana, V+1 (7a), IV+1 (7b).

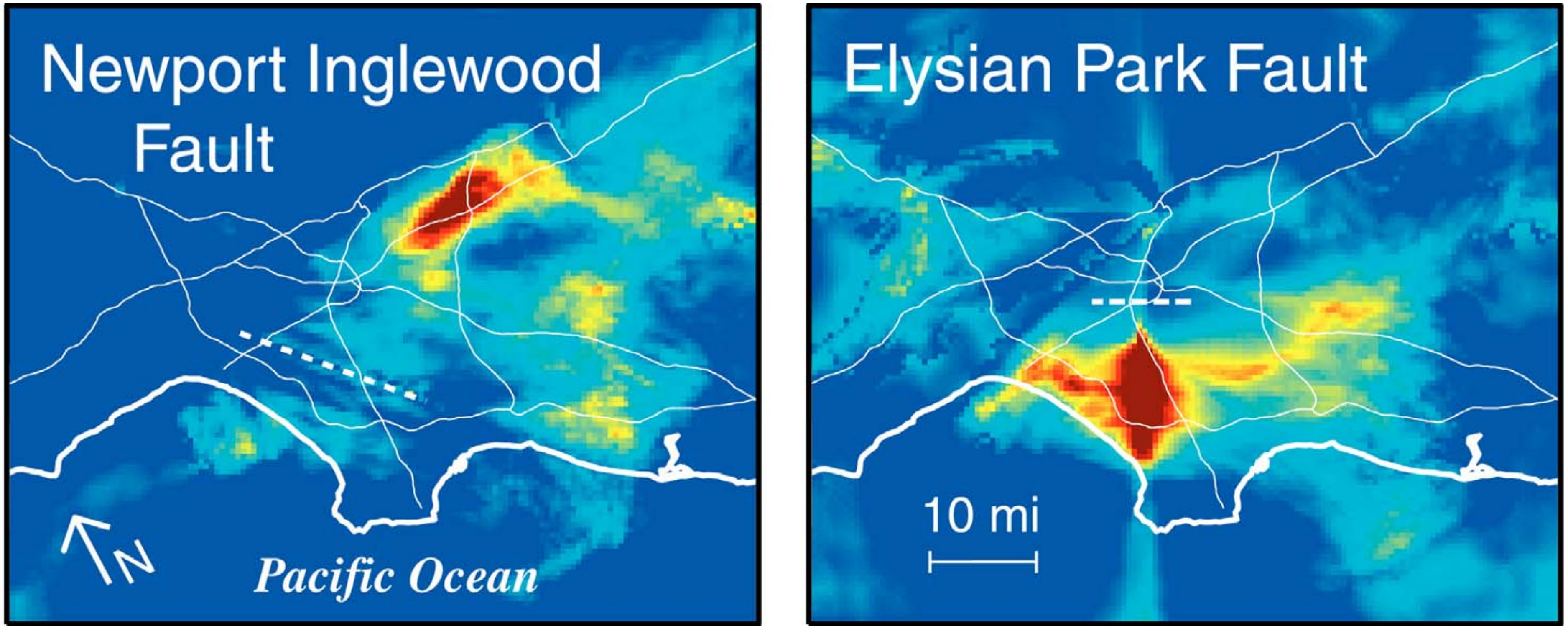
8) 7.09.1920, Garfagnana, IV+1 (8).

9) 12.12.1924, Carnia, IV+1 (9).

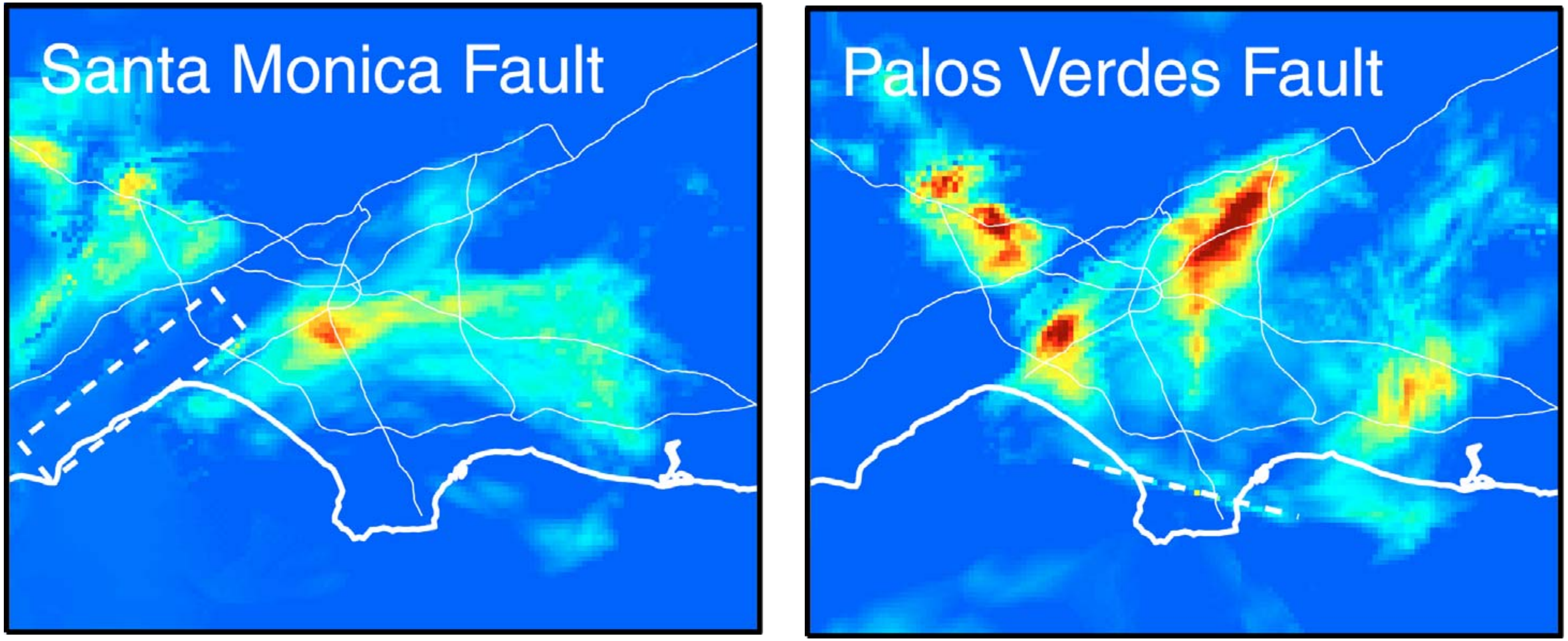
10) 15.05.1951, Lodigiano, V+1 (10).

11) 15.07.1971, Parmense, IV+1 (11).

Secondary parts (*thin line*) of the multi-connected isoseismals for the 11 earthquakes in the zone of Alpago earthquake.



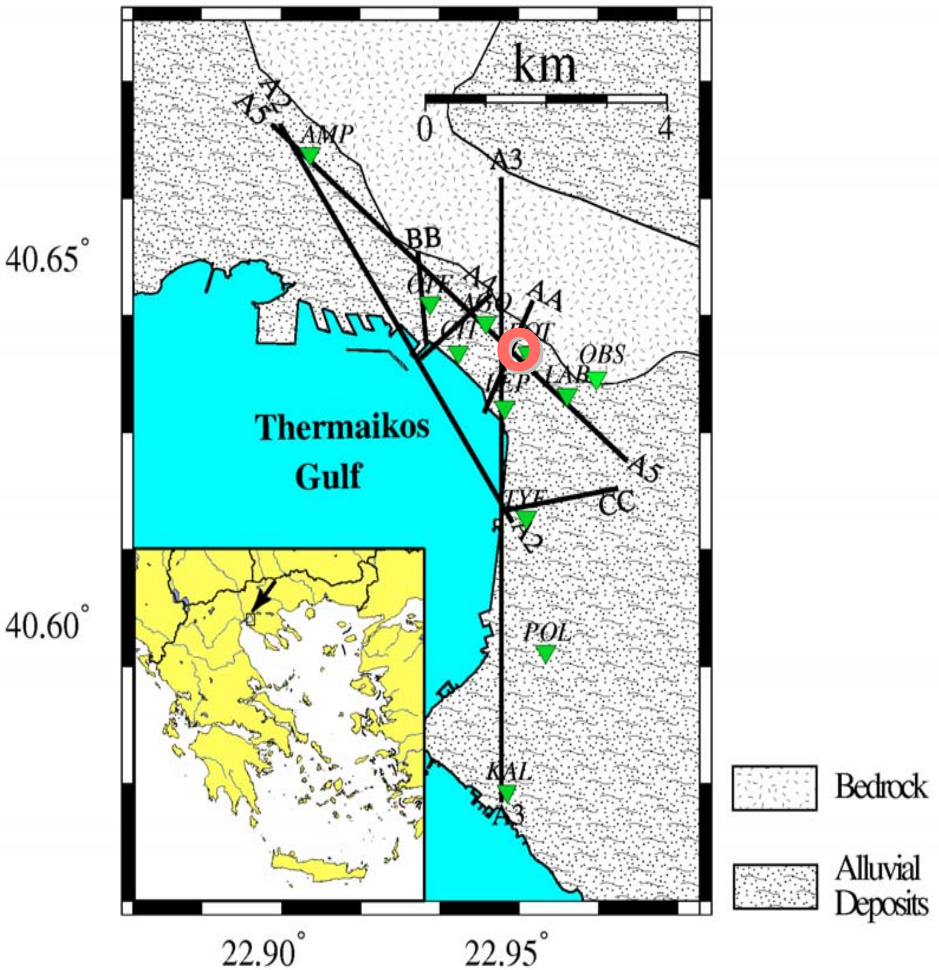
These images of the Los Angeles Basin show "hotspots" predicted from computer simulations of an earthquake on the Elysian Park Fault and an earthquake on the Newport-Inglewood Fault (represented by the white dashed lines). What is shown is **not** how much shaking was experienced at a particular site but rather how much more or less shaking (highest levels are shown in red) a site receives **relative to what is expected** from only the magnitude of the earthquake and the site's distance from the fault. These images consider only part of the total shaking (long-period motions) and were calculated by using a simplified geologic structure. (Data for images courtesy of Kim Olsen, University of California, Santa Barbara, SCEC Phase III report).



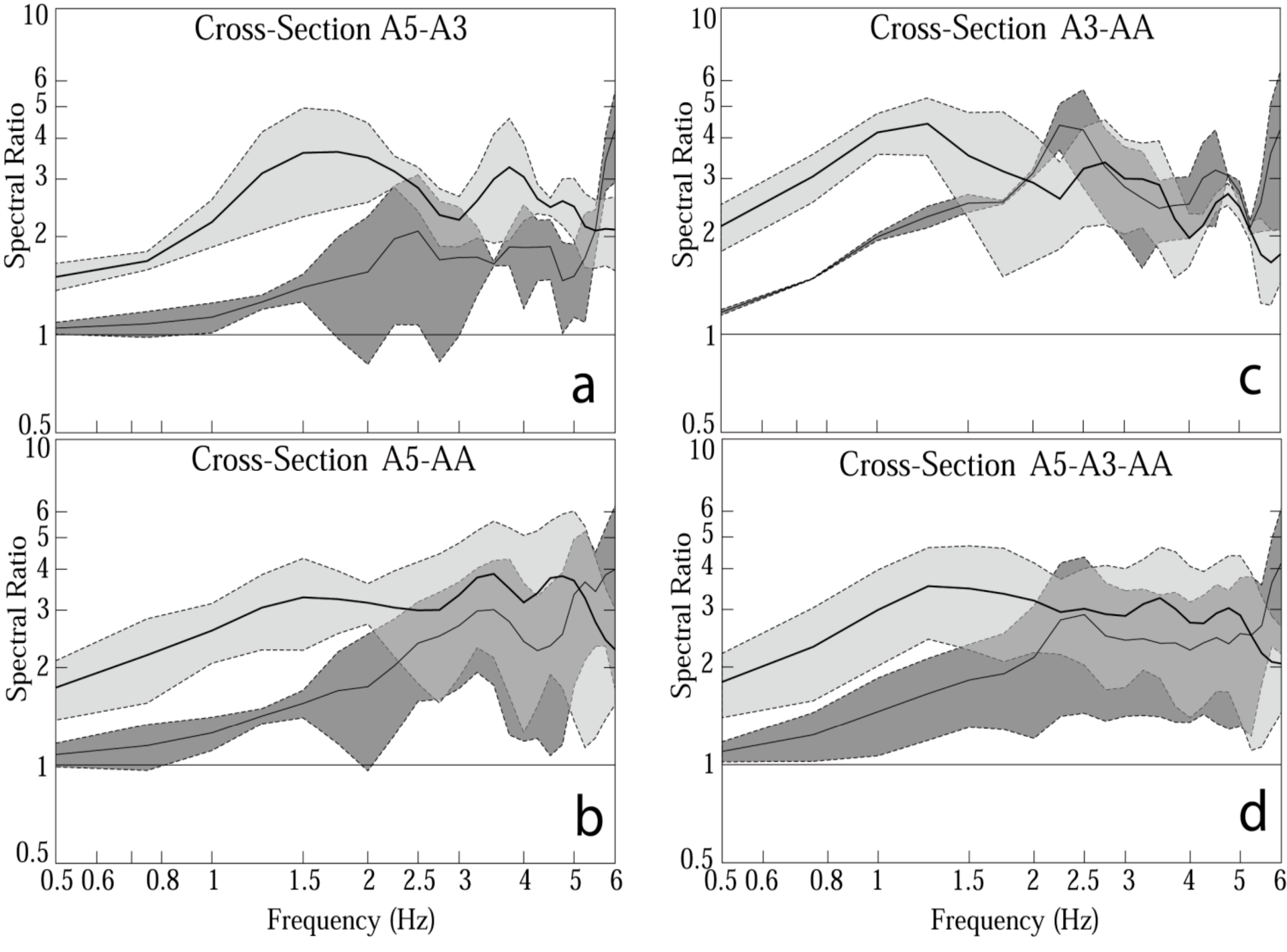
"hotspots" predicted from computer simulations of an earthquake on the Santa Monica Fault and an earthquake on the Palos Verdes Fault (represented by the white dashed lines). SCEC Phase III report, Field, 2000, BSSA, see also http://www.scec.org/phase3/

Spectral amplifications

- **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.



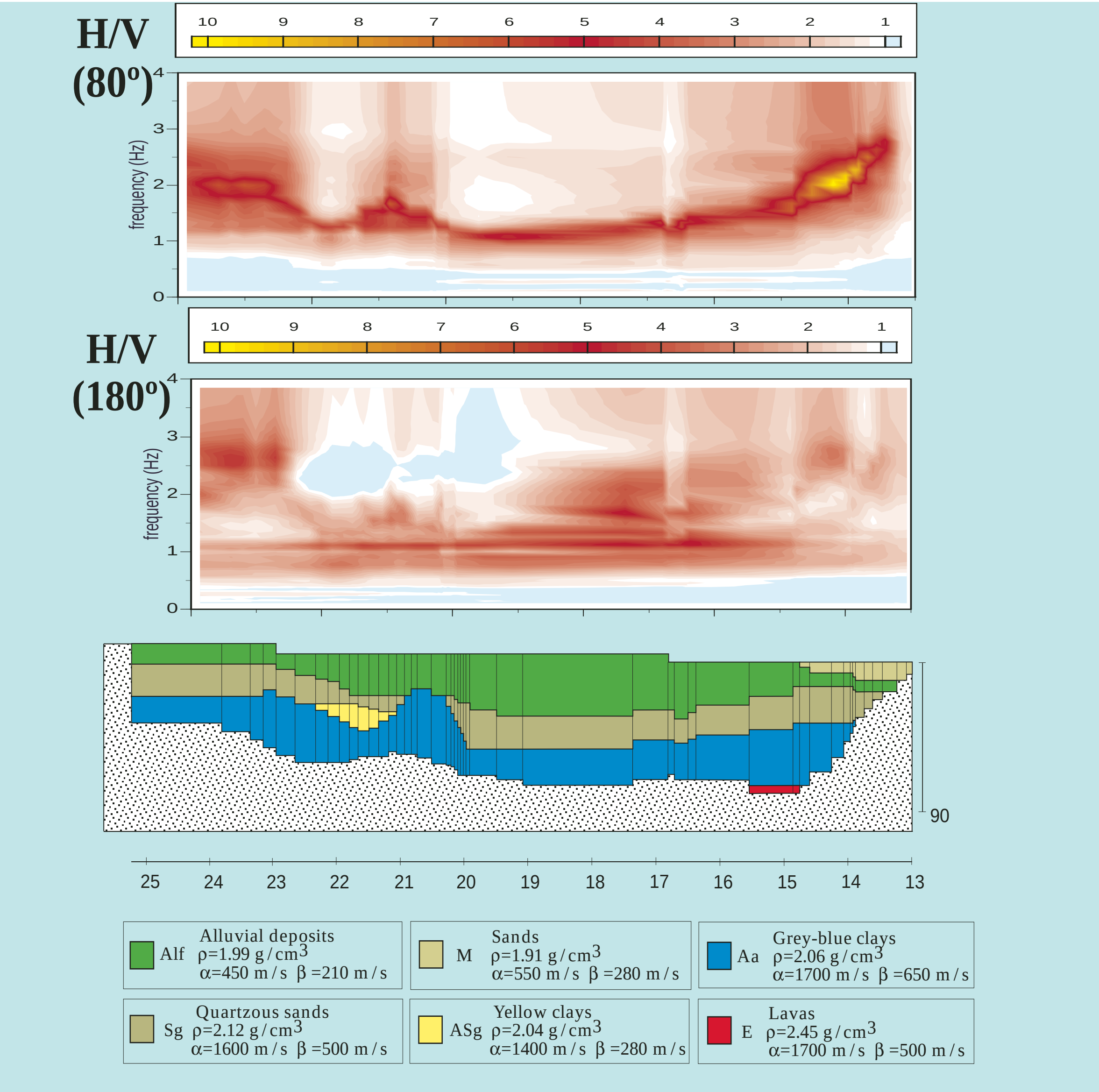
Thessalonica: profiles along which the seismic response has been estimated both theoretically and experimentally.



Average spectral amplifications at the common points of the cross-sections. Shaded areas indicate the +/-σ band for horizontal (light) and vertical (dark) components of motion.

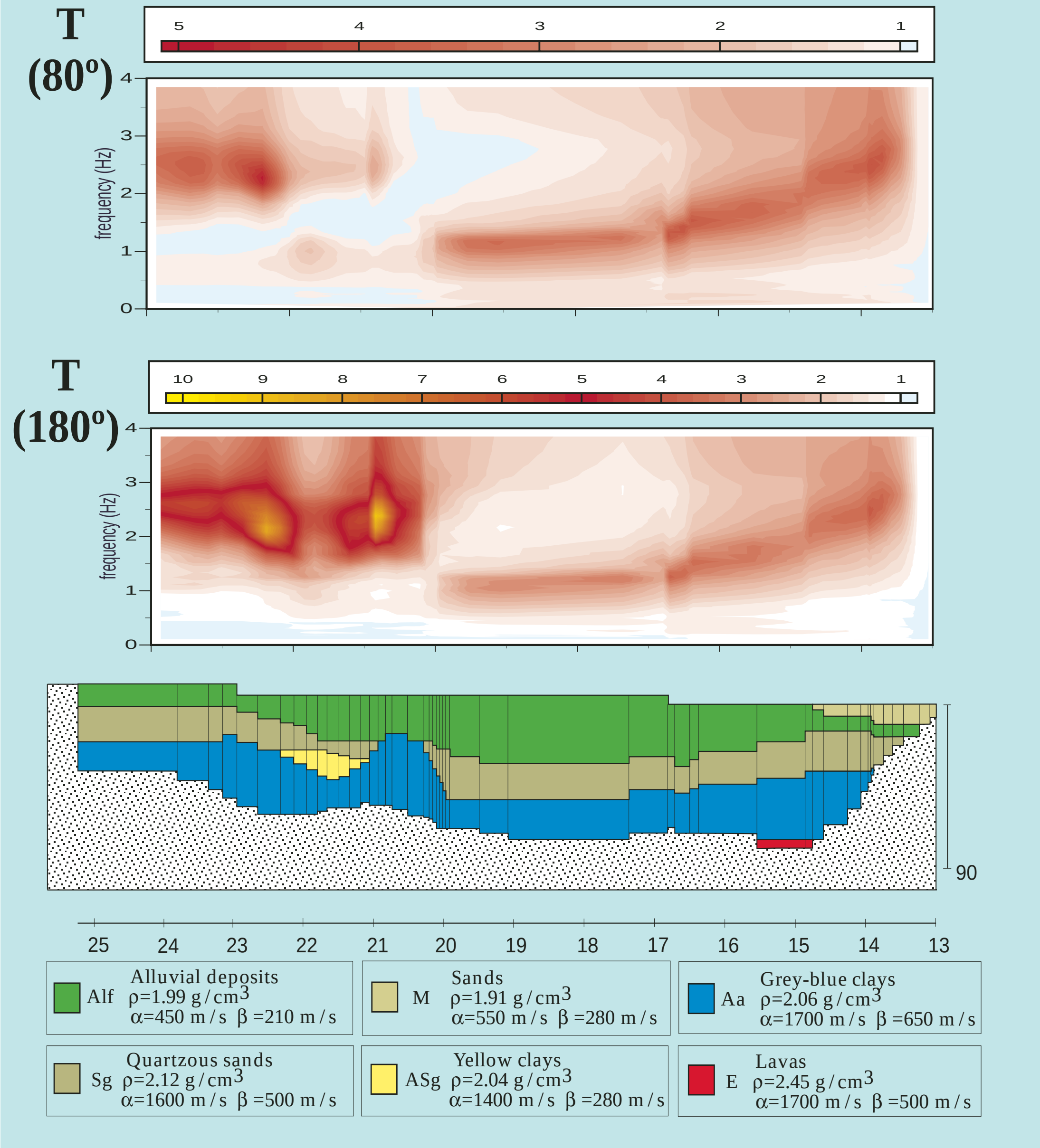
Modeling of seismic input

(azimuth effect)



Modeling of seismic input

(azimuth effect)



RSR for the SH component of motion

- The use of modelling is necessary because, contrary to the common practice, the so-called local site effects cannot be modelled by a convolutive method, since they can be ***strongly dependent upon the properties of the seismic source***.

- The wide use of realistic synthetic time histories, **which model the waves propagation from source to site**, allows us to easily construct scenarios based on significant ground motion parameters (acceleration, velocity and displacement).

WHY?

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 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.

In fact in the product $M_{ij}.m(t)$ 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.

In the frequency domain it may seem simpler because the above convolution is converted to pure multiplication:

$$u_k(\omega)=M_{ij}(\omega)\,\mathbf{.}\,G_{ki,j}(\omega)$$

and the equation is solved for each frequency separately. Within linearity we get $M_{ij}(\omega)$ but to split the source time function and the mechanism again a non-linear constraint is needed, so the advantage of the frequency domain is fictitious only.

The use of synthetic seismograms makes it available a large number of complete signals, whenever possible, calibrated against observations, to be fruitfully used by engineers in non-linear analysis of structures.

MICROZONATION

Earthquake 1.10.1995, Dinar, Turkey

A comprehensive description of the theory used to compute the synthetic signals is given in **Advances in Geophysics, Vol. 43, 2001, Academic Press**.

Our realistic modelling of ground motion drastically reduces the epistemic uncertainty of simplified methods, like the convolutive ones, and represents a quite powerful tool to quantify some of the effects of aleatory uncertainty, by parametric analysis.

- Therefore we can conclude, in agreement with the recent paper by Field and the SCEC phase III Working Group (2000), that **our best hope is via waveform modeling** based on first principles of physics.

UNESCO-IUGS-IGCP

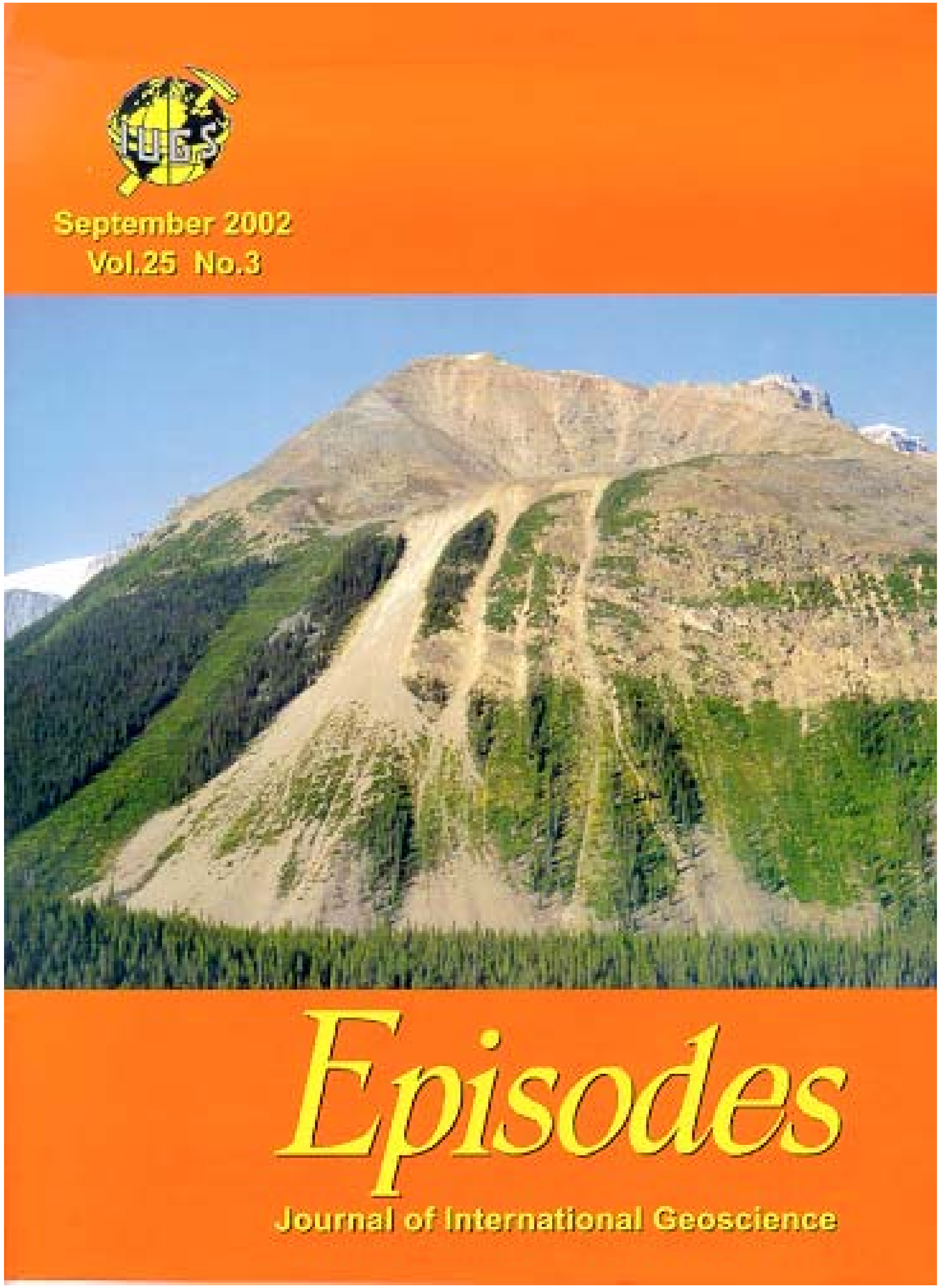
Project

- In the framework of the UNESCO-IUGS-IGCP project “Realistic Modelling of Seismic Input for Megacities and Large Urban Areas” , centred at the **Abdus Salam International Center for Theoretical Physics**, a deterministic approach has been developed and applied to several urban areas for the purpose of seismic microzoning.

The full text of the summary of the main results obtained can be downloaded at:

- http://www.ictp.trieste.it/

www_users/sand/unesco-414.html


September 2002
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Episodes

Journal of International Geoscience

Studied Urban areas:

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Beijing
Rome
Russe
Santiago de Cuba
Thessalonica
Sofia
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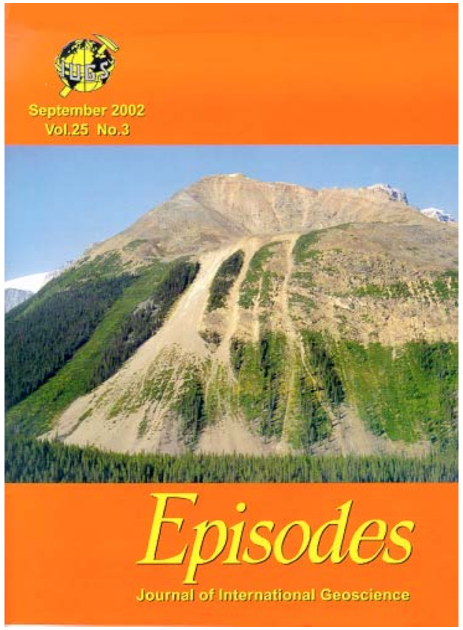
International working group



Giuliano F. Panza (Chairman), Leonardo Alvarez, Abdelkrim Aoudia, Abdelhakim Ayadi, Hadj Benhallou, Djillali Benouar, Zoltan Bus, Yun-Tai Chen, Carmen Cioflan, Zhifeng Ding, Attia El-Sayed, Julio Garcia, Bartolomeo Garofalo, Alexander Gorshkov, Katalin Gribovszki, Assia Harbi, Panagiotis Hatzidimitriou, Marijan Herak, Mihaela Kouteva, Igor Kuznetzov, Ivan Lokmer, Said Maouche, Gheorghe Marmureanu, Margarita Matova, Maddalena Natale, Concettina Nunziata, Imtyaz Parvez, Ivanka Paskaleva, Ramon Pico, Mircea Radulian, Fabio Romanelli, Alexander Soloviev, Peter Suhadolc, Gyõzõ Szeidovitz, Petros Triantafyllidis, Franco Vaccari.

CONCLUSIONS

A proper evaluation of the seismic hazard, and of the seismic ground motion due to an earthquake, can be accomplished by following a deterministic or scenario-based approach.

This approach allows us to incorporate all available information collected in a geological, seismotectonic and geotechnical database of the site of interest as well as advanced physical modeling techniques to provide a reliable and robust basis for the development of a deterministic design basis for civil infrastructures.

The robustness of this approach is of special importance for critical infrastructures. At the same time a scenario-based seismic hazard analysis allows to develop the required input for probabilistic risk assessment (PRA) as required by safety analysts and insurance companies.

The scenario-based approach removes the ambiguity in the results of probabilistic seismic hazard analysis (PSHA). The deterministic methodology is strictly based on observable facts and data and complemented by physical modeling techniques which can be submitted to a formalized validation process. By sensitivity analysis, knowledge gaps related to lack of data can be dealt with easily due to the limited amount of scenarios to be investigated.

In its probabilistic interpretation, the scenario-based approach is in full compliance with the likelihood principle and therefore meeting the requirements of modern risk analysis. The scenario-based analysis can easily be adjusted to deliver its output in a format required by safety analysts and civil engineers.

THE END