The Abdus Salam
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Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

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28 September - 10 October, 2009

Towards a society resilient to earthquake hazard: neo-deterministic time-variable assessment

G.F. Panza
University of Trieste/ICTP, SAND Group
Trieste

Towards a society resilient to earthquake hazard: neo-deterministic time-variable assessment

G.F. Panza and the SAND group

Ninth Workshop on
Non-linear Dynamics and Earthquake Predictions

Trieste, October 1 - 13, 2007

CHINA EARTHQUAKE ADMINISTRATION

UNIVERSITATEA DIN BUCURESTI

INTRODUCTION

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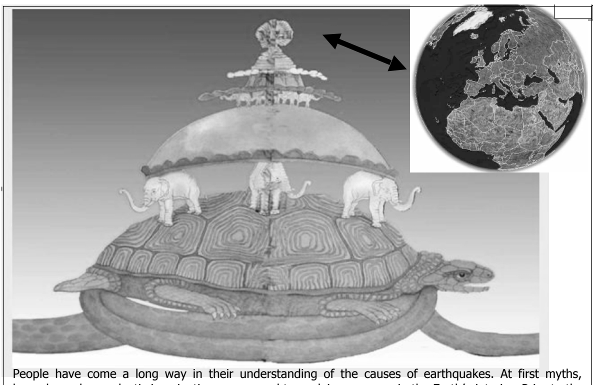

People have come a long way in their understanding of the causes of earthquakes. At first myths, legends, and apocalyptic imaginations were used to explain processes in the Earth's interior. Prior to the knowledge that the Earth is a sphere, the Earth was thought to be a disk carried by something. **Hindu mythology** taught that the god Vishnu, **preserver of the world,** is lying on the world snake3 On the turtle stand **four** elephants that carry the Earth. **Movement of the elephants causes earthquakes.**

Progresses in the mitigation of hazard can rely upon the control of the dance of the elephants!???

Certainly not!!

Seismic risk can be reduced only with the joint exploitation of advanced seismic engineering techniques and reliable methodologies for the assessment of seismic hazard.

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In **1660** *Robert Hooke* formulates de fundamental law of elasticity

Ut tensio sic vis

the base of the Physics of Seismology

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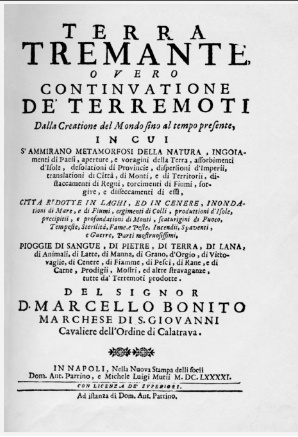

TERRA
TREMANTE
OVERO
CONTINVATIONE
DE' TERREMOTI
Dalla Creatione del Mondo fino al tempo presente,
IN CUI
S'AMMIRANO METAMORFOSI DELLA NATURA, INGOIAmenti di Paesi, aperture, e voragini della Terra, assorbimenti d'Isole, desolationi di Provincie, dispersioni d'Imperii, translationi di Città, di Monti, e di Territorii, distaccamenti di Regni, torcimenti di Fiumi, sorgive, e disseccamenti di essi,
CITTA RIDOTTE IN LAGHI, ED IN CENERE, INONDAtioni di Mare, e di Fiumi, ergimenti di Colli, produttioni d'Isole, precipitii, e profondationi di Monti, scaturigini di Fuoco, Tempeste, Sterilità, Fame, e Peste, Incendii, Spaventi, e Guerre, Parti mostruosissimi,
PIOGGIE DI SANGUE, DI PIETRE, DI TERRA, DI LANA, di Animali, di Latte, di Manna, di Grano, d'Orgio, di Vittovaglie, di Cenere, di Fiamme, di Pesci, di Rane, e di Carne, Prodigii, Mostri, ed altre stravaganze, tutte da' Terremoti prodotte.
DEL SIGNOR
D. MARCELLO BONITO
MARCHESE DI S. GIOVANNI
Cavaliere dell'Ordine di Calatrava.

IN NAPOLI, Nella Nuova Stampa delli socii Dom. Ant. Parrino, e Michele Luigi Mutii M. DC. LXXXXI.
CON LICENZA DE' SUPERIORI.
Ad istanza di Dom. Ant. Parrino.

In 1691 the Author describes the effects of the catastrophic earthquake that December 5, 1456 shook L'Aquila and neighbors and produced severe damages to a region very similar to the one affected by the catastrophic event of April 6, 2009.

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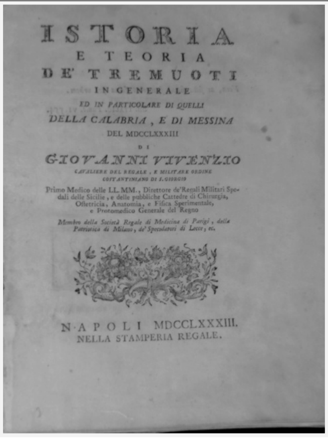
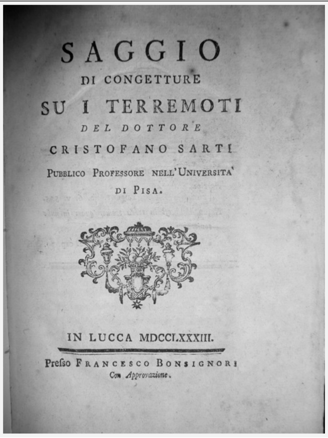
Only in 1760, the scientific community, thanks to the work of John Michell, recognized that earthquakes and volcanic eruptions are endogenous natural phenomena of the Earth.



ISTORIA
E TEORIA
DE' TREMUOTI
IN GENERALE
ED IN PARTICOLARE DI QUELLI
DELLA CALABRIA, E DI MESSINA
DEL MDCCLXXXIII
DI
GIOVANNI VIVENZIO
CAVALIERE DEL REGALE, E MILITARE ORDINE COSTANTINIANO DI S. GIORGIO
Primo Medico delle LL. MM., Direttore de' Regali Militari Spedali delle Sicilie, e delle pubbliche Cattedre di Chirurgia, Ostetricia, Anatomia, e Fisica Sperimentale, e Protomedico Generale del Regno
Membro della Società Regale di Medicina di Parigi, della Patriotica di Milano, de' Speculatori di Lecce, ec.

NAPOLI MDCCLXXXIII.
NELLA STAMPERIA REGALE.

In the late 1700, stimulated by the study on electricity, electroseismic theories are formulated and in analogy with Benjamin Franklin (lightning rod), Pierre Bertholon conceives the idea of an "earthquake rod" (Journal de physique, 1779). Giovanni Vivenzio in his book "Historia e Teoria de tremuoti in generale ed in particolare di quelli della Calabria e di Messina del 1783", published the same years says that: "...i tremuoti non sono altro che tuoni sotterranei siccome Plinio l'ha conosciuto anticamente; e poiché è dimostrato che il tuono è effetto di elettricità, non si può far di meno di riconoscere la materia elettrica per cagione dei tremuoti".


SAGGIO
DI CONGETTURE
SU I TERREMOTI
DEL DOTTORE
CRISTOFANO SARTI
PUBBLICO PROFESSORE NELL' UNIVERSITA'
DI PISA.

IN LUCCA MDCCLXXXIII.
Presso FRANCESCO BONSIGNORI
Con Approvazione.

Cristofano Sarti, in his book, published in 1788 works out a series of conjectures about the endogenous origin of the earthquake and he has the great merit to point out that earthquakes and volcanoes are natural phenomena not necessarily correlated.

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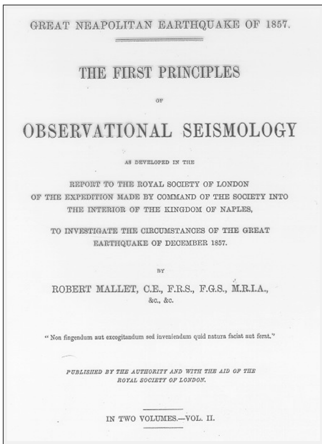

GREAT NEAPOLITAN EARTHQUAKE OF 1857.

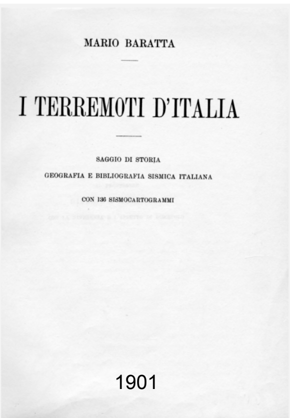
THE FIRST PRINCIPLES
OF
OBSERVATIONAL SEISMOLOGY
AS DEVELOPED IN THE
REPORT TO THE ROYAL SOCIETY OF LONDON
OF THE EXPEDITION MADE BY COMMAND OF THE SOCIETY INTO
THE INTERIOR OF THE KINGDOM OF NAPLES,
TO INVESTIGATE THE CIRCUMSTANCES OF THE GREAT
EARTHQUAKE OF DECEMBER 1857.
BY
ROBERT MALLET, C.E., F.R.S., F.G.S., M.R.I.A.,
&c., &c.

"Non fingendum aut excogitandum sed inveniendum quid natura faciat aut ferat."

PUBLISHED BY THE AUTHORITY AND WITH THE AID OF THE
ROYAL SOCIETY OF LONDON.

IN TWO VOLUMES.—VOL. II.

The Irish engineer Robert Mallet, with a grant of 150 pounds from the Royal Society of London, invited by Francesco II di Borbone, made a scientific survey of the most damaged area by the 1857 earthquake. Mallet collected all his observations in a monumental publication (1862) the Royal Society of London that represents the first attempt to apply systematically the basic principles of Physics to the effects of earthquakes


MARIO BARATTA

I TERREMOTI D'ITALIA

SAGGIO DI STORIA
GEOGRAFIA E BIBLIOGRAFIA SISMICA ITALIANA
CON 136 SISMOCARTOGRAMMI

1901

1902 *Giuseppe Mercalli* publishes the macrosesimic Intensity scale.

1907 *Vito Volterra* publishes the theory of dislocation, based on Somigliana solution of Navier equations and he opens the way to the study of the Physics of seismic sources.

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Italy is the forefront of seismological research and seismic hazard mitigation till the beginning of 1900. There is a severe and guilty decline, mostly due to governmental deficiencies, that is reversed for the first time after the 1976 Friuli earthquake. This constructive trend seems to continue in 2003 after the San Giuliano di Puglia earthquake of 2002 and after the 2009 l'Aquila earthquake. The activity of ICTP started in 1980 is certainly a part of this Renaissance, with a special attention to prevention.

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Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did NOT happen.

\- Kofi Annan,1999

The evaluation of seismic hazard is based on the traditional Probabilistic Seismic Hazard Analysis, i.e. on the probabilistic analysis of earthquake catalogues and of ground motion, from macroseismic observations and instrumental recordings. This leads to severe bias in the estimation of seismic hazard, with artificially inflated errors, because the mathematical model of PSHA, as it is in use today, is inaccurate and leads to systematic errors in the calculation process.

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Recently this approach showed its limitation in providing a reliable seismic hazard assessment, possibly due to the insufficient information about historical seismicity, which can introduce relevant errors in the purely statistical approach mainly based on the seismic history.

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? GSHAP ?
Checking forecasted values against observations

The probabilistic analysis supplies indications that can be useful but seem not sufficiently reliable to characterize seismic hazard.

Lessons from recent earthquakes: Kobe (17.1.1995), Gujarat (26.1.2001), Boumerdes (21.5.2003), Bam (26.12.2003) and Eastern Sichuan (12.5.2008)

	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
E-Sichuan	0.16-0.24	0.6->0.8

To overcome the mentioned limitations and, above all, to improve the pre-seismic information which may lead to an effective mitigation of seismic risk, we are following an innovative approach, that combines Earth Observation (EO) data and new advanced approaches in seismological and geophysical data analysis.

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ASI Pilot Project - SISMA

"Seismic Information System for Monitoring and Alert"

R. Sabadini[1], R. Barzaghi[2], G.F. Panza[3,6], M. Fermi[4], B. Crippa[1], A. Peresan[3], F. Vaccari[3], A. Aoudia[6], F. Romanelli[3], R. Riva[1], A. M. Marotta [1], S. Zoffoli[5] and R. Guzzi[5]

(1) Dipartimento di Scienze della Terra, Università di Milano, Italy
(2) Dipartimento di Scienze della Terra, Università di Trieste, Italy
(3) Politecnico di Milano, Italy
(4) Galileian Plus, Italy
(5) Agenzia Spaziale Italiana, Sezione Osservazione della Terra
(6) The Abdus Salam International Centre for Theoretical Physics. Trieste, Italy

Università di Milano

Politecnico di Milano

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The system we are developing is based on the neodeterministic approach for the estimation of seismic ground motion, integrated with the space and time dependent information provided by EO data analysis through geophysical forward modeling.

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The need of integration of different geophysical observables is obvious when the process of earthquake preparation and occurrence is analysed: the lithosphere - a hierarchical system of interacting blocks - accumulates stress, according to strain and strain rates fields due to tectonics, which is partly released during the earthquake occurrence.

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System's Overall Description

Seismological data analysis

- **INPUT**

Data on seismicity (earthquake catalogues), geomorphology and geodynamics and Earth structure (velocity, gravity data);

Worldwide tested pattern recognition algorithms for middle-range intermediate-term earthquake prediction and for identification of damaging earthquake prone areas;

Robust and tested codes for the earth structure retrieval and numerical modelling of lithosphere block dynamics.

Seismological data analysis

- **OUTPUT (1)**

Regional alerted areas by the near real time monitoring of seismicity (TIPs for the occurrence of earthquakes with $M \geq M_0$);

Maps of the morphostructural zonation and selection of seismogenic nodes prone to earthquakes with M≥6.0 & M≥6.5 within the alerted regions;

Seismological data analysis

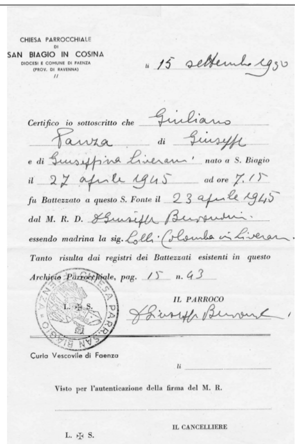
- **OUTPUT (2)**

Restrained local alerted areas for GPS and SAR investigations;

Multiscale velocity models of the Earth Structure for geophysical forward modelling;

Preferred models for the dynamics of the lithosphere at a regional scale.

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


CHIESA PARROCCHIALE
DI
SAN BIAGIO IN COSINA
DIOCESI E COMUNE DI FAENZA
(PROV. DI RAVENNA)

li 15 settembre 1950

Certifico io sottoscritto che Giuliano Panza di Giuseppe e di Giuseppina Liverani nato a S. Biagio il 27 aprile 1945 ad ore 7.15 fu Battezzato a questo S. Fonte il 23 aprile 1945 dal M. R. D. Giuseppe Bernardini essendo madrina la sig. Colli Colomba in Liverani. Tanto risulta dai registri dei Battezzati esistenti in questo Archivio Parrocchiale, pag. 15 n. 43

L. ✠ S.

IL PARROCO

Curia Vescovile di Faenza

li

Visto per l'autenticazione della firma del M. R.

IL CANCELLIERE

L. ✠ S.

My earliest credential about prediction

This is my certificate of baptism, drafted on September 15, 1950, stating that I was **born** on April **27**, 1945 and I was **christened** on April **23**,1945

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Intermediate-term middle-range earthquake prediction experiment

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)*

Intermediate-term middle-range earthquake prediction experiment in Italy

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:

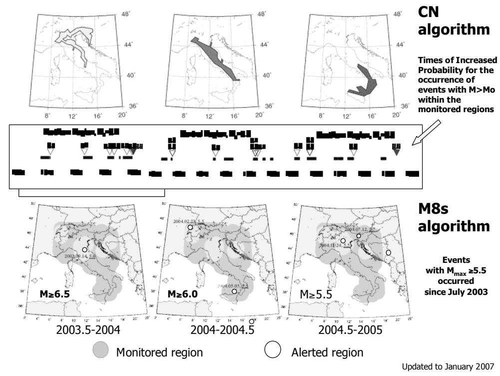
- **Variations in the seismic activity**
- **Seismic quiescence**
- **Space-time clustering of events**

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

Intermediate-term middle-range earthquake prediction experiment in 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.

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 September 1 2009; next updating November 1 2009)

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

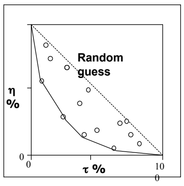
Intermediate-term middle-range earthquake prediction

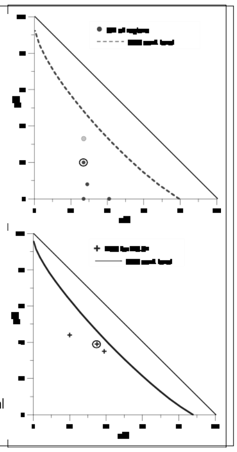
Evaluation of prediction results

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 Ital

Updated to September 1 2009 (next updating November 1 2009)

Morphostructural zonation and pattern recognition of earthquake prone areas

Morphostructural zonation and pattern recognition of earthquake prone areas

- **The Morphostructural Zonation method, MSZ *(Alekseevskaya et al., 1977),* allows to identify, independently from earthquake catalogues information, the sites where strong earthquakes are likely to occur.**

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

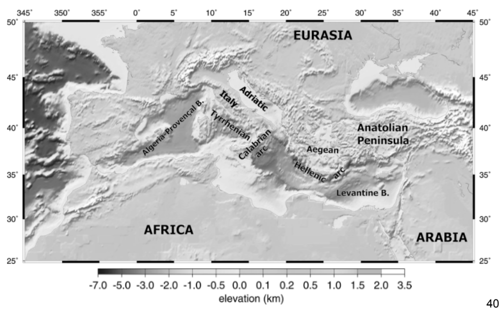
⇩

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 (~ 85% of the total) that occurred in some of the nodes previously recognized to be the potential sites for the occurrence of strong events.



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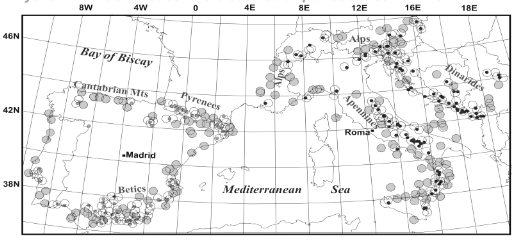
Recognition of nodes where strong earthquakes may nucleate in the Mediterranean area

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.

Multiscale Neo-deterministic Hazard Scenarios

Regional seismic hazard scenarios
(ground motion at bedrock)

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

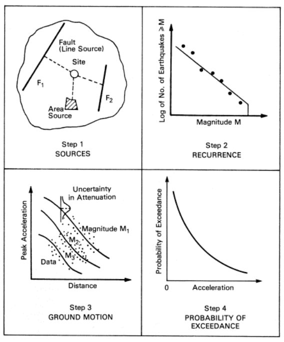


FIGURE 10.2 Basic steps of probabilistic seismic hazard analysis (after TERA Corporation 1978).

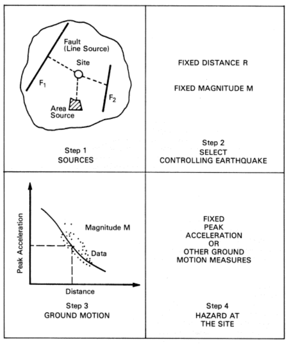


FIGURE 4.1 Basic steps of deterministic seismic hazard analysis (after TERA Corporation 1978).

Probabilistic and Deterministic

procedures after Reiter (1990)

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Probabilistic

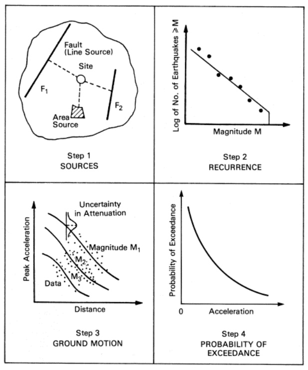

FIGURE 10.2 Basic steps of probabilistic seismic hazard analysis (after TERA Corporation 1978).

Step 2 - Recurrence can be represented by a linear relation only if the size of the study area is large with respect to linear dimensions of sources.
Step 3 - Attenuation relations are not translation invariant in the phase space (M, R, S)), i.e. the relative decay is independent from (M, R, S). Even when translation invariant they are not a conditional probability density function, they represent the functional dependency of the random spectral acceleration on the random variates, magnitude, distance and measurement error (Klügel, 2006).

Step 4 - ???

M - magnitude; R - source distance; S - local soil conditions

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Deterministic

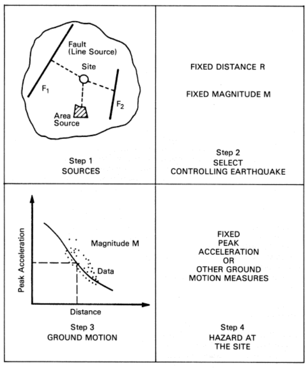
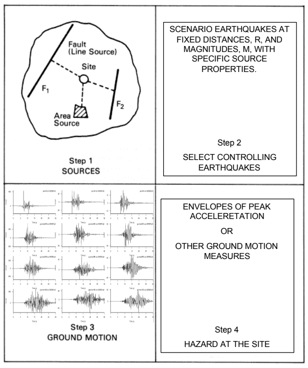


FIGURE 4.1 Basic steps of deterministic seismic hazard analysis (after TERA Corporation 1978).

Step 3 - Most of the attenuation relations are not translation invariant in the phase space (M, R, S)), i.e. the relative decay is independent from (M, R, S). Even when translation invariant they are not a conditional probability density function, they represent the functional dependency of the random spectral acceleration on the random variates, magnitude, distance and measurement error (Klügel, 2006).

M - magnitude; R - source distance; S - local soil conditions

NEO-DETERMINISTIC



New approach based on synthetic signals computation

No need of attenuation relations

The laws of multivariate theory of probability are applied, as a rule, to calculate the conditional probability of exceedance of a certain hazard level z for a given set of parameters *m* and *r* by developing the joint probability density distribution for the spectral acceleration and relating it to the marginals of *m* and *r* (assuming independence between *m* and *r*).

The PSHA model is simplified by assuming that g(m,r) is constant and all the randomness of the problem is concentrated in the error term $\varepsilon\sigma$ (univariate approximation). As a result of the simplification for the probabilistic model we get:

$$\ln (S_a(m,r))=E(g(m,r))+\varepsilon\sigma \quad (2)$$

By multiplying the simplified equation (2) with the probability density function of ε, performing integration and converting the resulting expression to the complementary probability distribution function one can separate the randomness from the "quasi-deterministic" calculation of ground motion calculation.

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This simplifying replacement is completely incorrect from the point of view of mathematics because a random parameter is replaced by a number, by its expected value and this introduces a systematic error. This can be shown by replacing the distribution *g(m,r)* by a series (assuming that the development into a series is possible, which is the case here) around its expected value *E(g(m,r))*.

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[redacted]	[redacted]	[redacted]	

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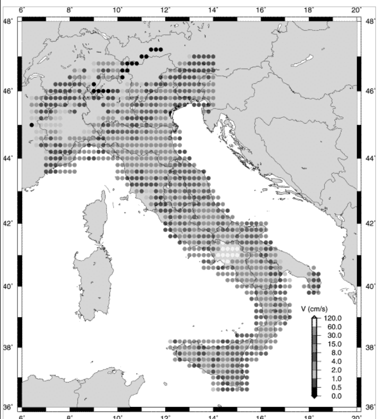


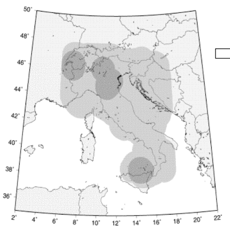
Neo-Deterministic hazard scenarios at national scale Time independent

PGV: Maximum estimated velocity Scenarios at bedrock

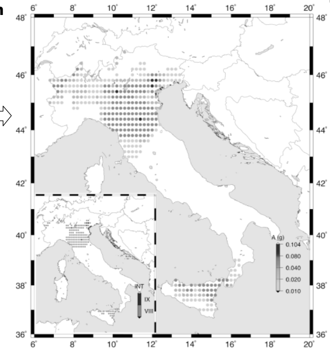
Neo-deterministic Method

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

Prediction of earthquakes with M5.5+

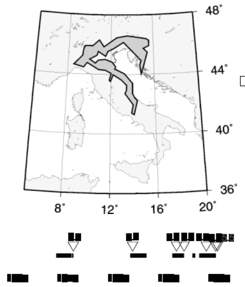


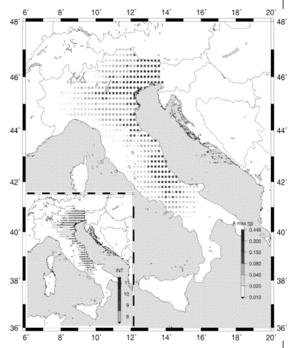
Alerted areas by M8S algorithm
for an earthquake with 5.5≤M<6.0
(as on 1 July 2006 – 1 January 2007)



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

Northern Region
Prediction of earthquakes with M≥5.4

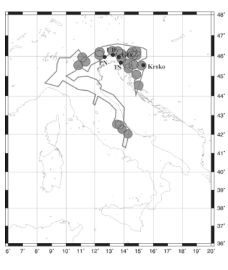


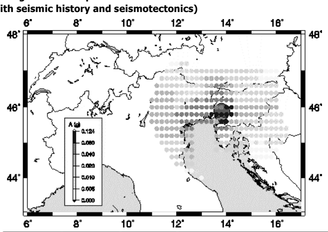


Scenario associated to earthquake prone nodes

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		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.

April 6, 2009 L'Aquila earthquake

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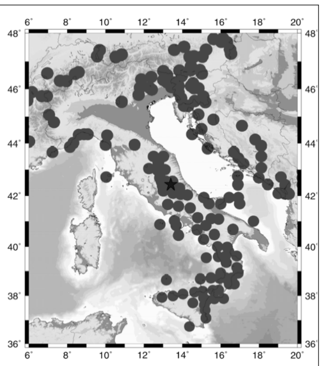
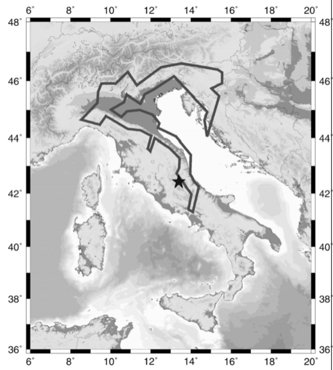
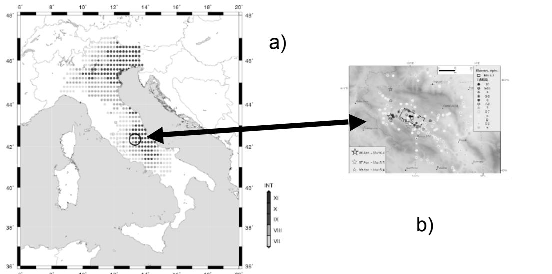
The epicenter (★) of L’Aquila earthquake of April 6, 2009 is within an area (red circles) previously identified as capable of earthquakes with M≥6.0, by pattern recognition analysis of morfostructural zonation (MSZ).



On Aprile 6, 2009 a CN alarm was active in the region delineated by the red line; The epicenter of the earthquake falls just outside (about 10 km) the alarmed region.

The earthquake occurred outside of the areas alarmed either by CN or M8S: thus it is **a failure to predict**.





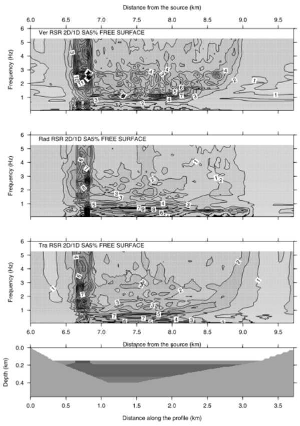
Nevertheless the shaking scenario (seismic ground motion at the bedrock) computed as a consequence of the alarm (a), has correctly predicted the macroseismic intensities observed after the April 6, 2009 earthquake (b).

Multiscale Neo-deterministic Hazard Scenarios

Detailed scenarios of ground motion including local site effects

Modellazioni, basate su di un profilo disponibile in letteratura, mostrano amplificazioni del moto del suolo anche di 10 volte in corrispondenza dei sedimenti alluvionali del fiume Aterno.

Le amplificazioni si manifestano in un ampio intervallo spettrale, ponendo quindi a rischio varie classi di edifici, e spiegano, almeno in parte, la distribuzione a macchia di leopardo dei danni.

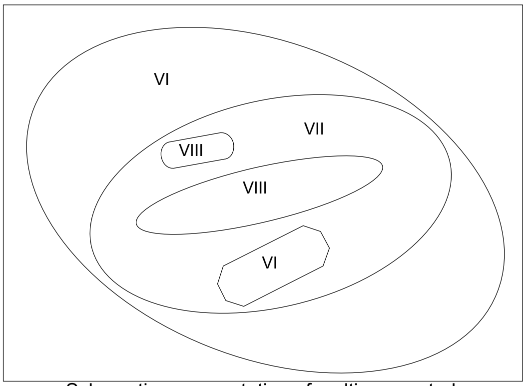


Effects of local soil conditions

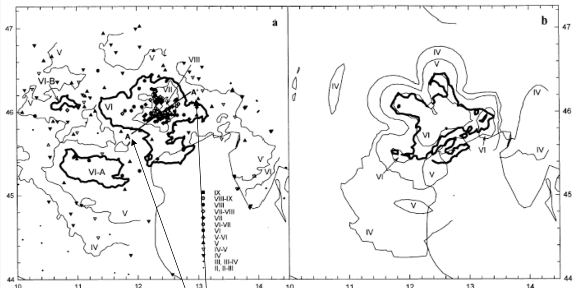
Isoseismals shape

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.

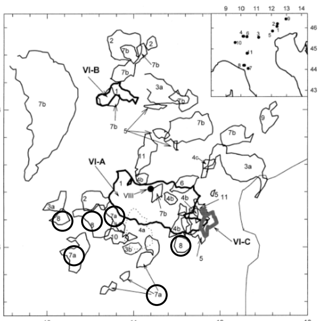


Schematic representation of multi-connected isoseismals (secondary parts in color)



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).

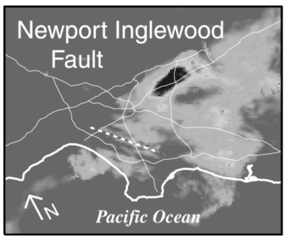
8) 7.09.1920, Garfagnana, IV+1 (8).

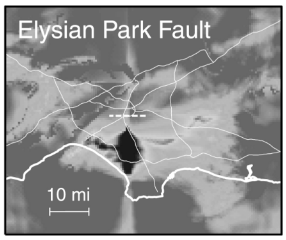
9) 12.12.1924, Carnia, IV+1 (9).

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

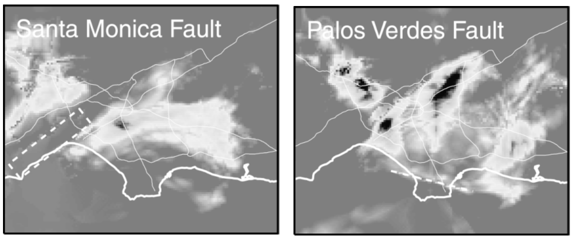
11) 15.07.1971, Parmense, IV+1 (11).

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/

- 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?

Formal problem

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:

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

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. There is no problems if the source force is a singlet.

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

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

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.

Good news towards implementation:

An agreement has been renewed 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 will be made available to the Civil Defence (end user).

Glaciation and earthquakes

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Snow load effect on seimicity

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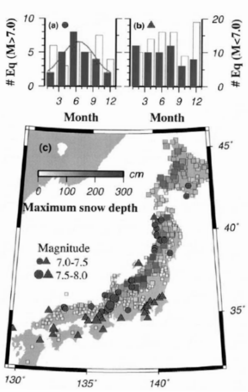

Number of earthquakes occurred in 2-month intervals, within (a) and outside (b) the snowy region. Red and white histograms show M≥7.0 (left) and 7.0>M≥6.0 (right) events, respectively. In (c) blue squares show maximum snow depths in a winter at AMeDAS stations (only points with snows deeper than 20.0 cm are shown). Epicenters of M≥7.0 earthquakes are shown in (c) as circles (snowy region) and triangles (outside). Red curve in (a) is the best-fit probability density function of the earthquake occurrence based on the two-component (stationary and annual) model (Heki, EPSL, 2003).

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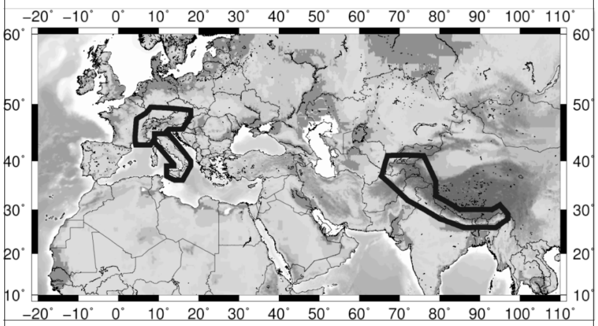

Study regions: Apennines, Alps, Himalaya

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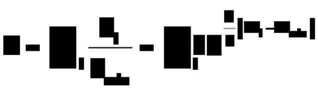
Seismicity is quantified by means of N (number of events) and Σ. Σ is based on Benioff strain release (Benioff, 1951) S_i, computed for each earthquake *i* with magnitude M_i, and normalized to the strain S_{min} of the minimum magnitude M_{min} considered for the analysis, that is:



where for the constant *d* we use the value *d*=1.5 given by Gutenberg and Richter (1956).

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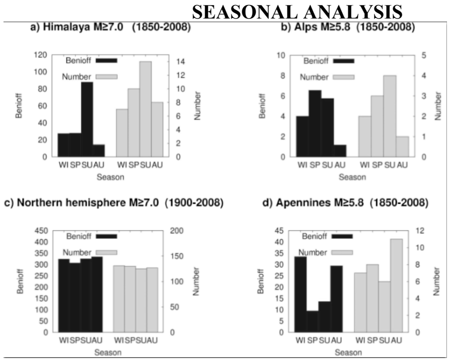
SEASONAL ANALYSIS



For the Northern hemisphere, if Alpine and Himalayan events are removed, the flat shape of the histograms remains unchanged.

Histograms of Σ and N (winter starting on **1 December**) for the crust events which occurred in the a) Himalayan region, b) Alps, c) Northern hemisphere and d) Apennines.

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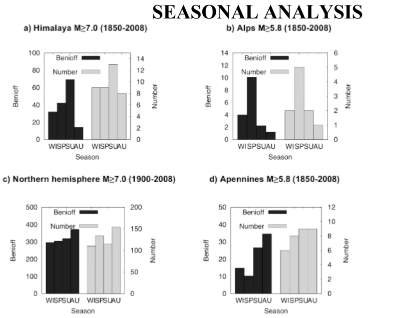
SEASONAL ANALYSIS



For the Northern hemisphere, if Alpine and Himalayan events are removed, the flat shape of the histograms remains unchanged.

Histograms of Σ and N (winter starting on **31 December**) for the crust events which occurred in the a) Himalayan region, b) Alps, c) Northern hemisphere and d) Apennines.

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Effect of past temperatures and climate changes on seismicity

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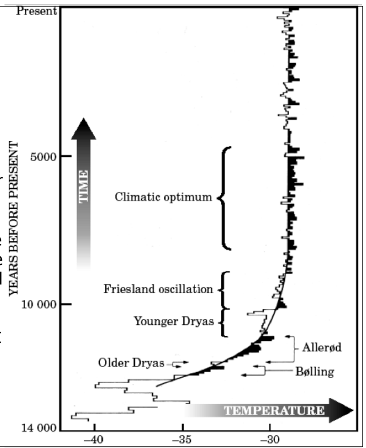
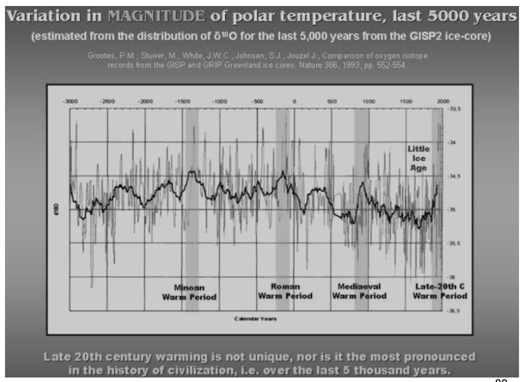
Cores from the ice at Camp Century, processed on the spot, in 1964 revealed ancient climate changes in unprecedented detail. The ratio of O18/O16 isotopes in the annual snow layers serves as a thermometer. Part per thousands variations to the right indicate warmer temperatures; those to the left, cooler ones. The large rise in temperature started about 14,000 years ago at the end of the last ice age. The plot also shows 1–2°C temperature leaps even within the one-century resolution of the data. (S. Weart, Physics today, August 2003)





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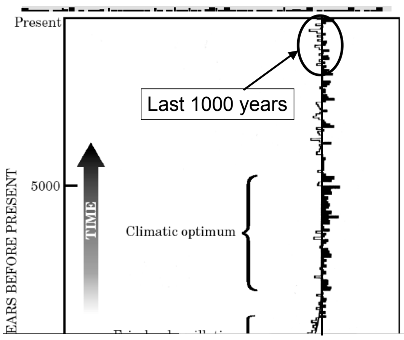

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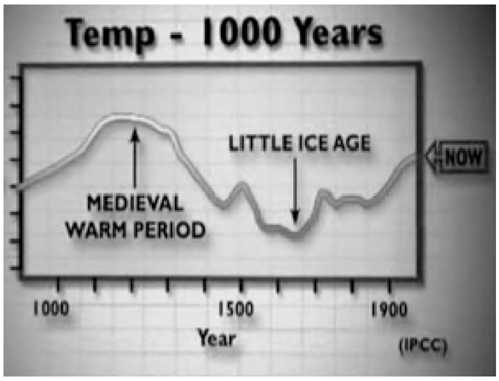

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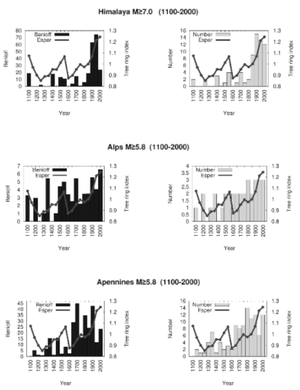

Secular analysis

Histograms showing Σ and N, in 50-year bins for the considered areas and average surface atmosphere temperature after Esper (2002). The quantitative estimate of the statistical significance of the correlation between seismicity and temperature variation is given in the following Table.

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[illegible]

[illegible]	Σ [illegible]	[illegible]	Σ [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-[illegible]	[illegible]

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Conclusions

- **The neo-deterministic seismic hazard procedure makes it possible the combined use of wide geophysical and geological data sets, knowledge of the physical process of earthquake generation and wave propagation in realistic anelastic media, and does not need to rely only on macroseismic observations, the key basis for most earthquake catalogues.**

Conclusions

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

Conclusions

- **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*).**

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.**

Conclusions

- **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.**

Conclusions

- **One of the advantages of the proposed approach consists in 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).**

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THE END

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