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Analysis of earthquake catalogs for intermediate-term predictions and seismic hazard assessment

Antonella Peresan

University of Trieste/SAND-ICTP
Trieste
Italy

ICTP Advanced School on
Understanding and Prediction of Earthquakes and other Extreme Events in Complex Systems
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Analysis of earthquake catalogs for intermediate-term predictions and seismic hazard assesment

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Contributed:
V. Kossobokov, L. Romashkova, A. Nekrasova, A. Harbi, H.M. Hussein, P.O. Ogwari

Department of Geosciences

The Abdus Salam International Centre for Theoretical Physics

E-mail: aperesan@units.it

Outline

- Heterogeneity of earthquake catalogs
- Intensity scales
- Multiscale approach to earthquake catalogs analysis
- Examples of catalogs analysis
  - Narrow scale: volcanic earthquakes
  - Intermediate scale: the earthquake catalogs for Italy
  - Large scale: toward a unified catalog for North Africa

What is an earthquake catalog?

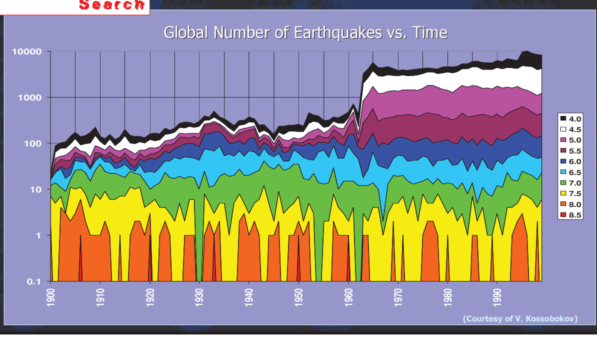
- An earthquake catalog is a collection of information about a set of seismic events, basically including:
  - Origin time
  - Location
  - Size of the earthquakes
- Additional information can be provided, ranging from related damage to seismic source parameters.
- A catalog may include several magnitude estimations, generally with a precision of one digit, even if values provided by different agencies may differ more than one unit.

What is an earthquake catalog?

- Catalogs are compiled for different purposes and by different agencies. Therefore they differ in:
  - geographical coverage
  - time span
  - level of detection
  - criteria of compilation
  - type and quality of earthquake data
- Consequence: no unique catalog for a given territory… but usually an heterogeneous set of catalogs (historical, instrumental, local, global, etc.), not always comparable, which may require different tools of analysis.
- A positive step forward: compilation of global catalogs (e.g. USGS-NEIC and ISC)

The USGS/NEIC Global Hypocenter Data Base

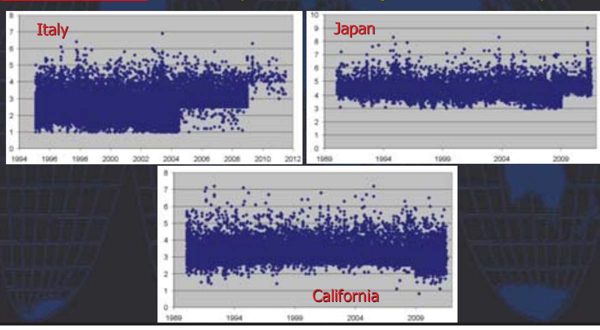
http://earthquake.usgs.gov/earthquakes/eqarchives/epic/



(Courtesy of V. Kossobokov)

The USGS/NEIC Global Hypocenter Data Base

"The **NEIC PDE catalog** contains data for M2.5 and greater U.S. earthquakes and M4.5 and greater Worldwide earthquakes."



The ISC Global Data Base

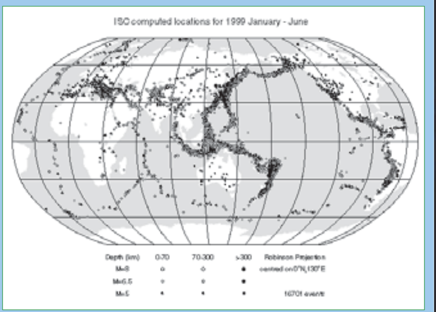
http://www.isc.ac.uk/

International Seismological Centre

Bulletin of the International Seismological Centre (revised & unrevised)

Data Contributed by Agencies

Data from Special Projects



Measures of earthquakes size

- The information about the size of historical earthquakes is generally provided in terms of earthquake intensity, i.e. a quantitative estimation based on the observed damage.
- The concept of earthquake magnitude, based on instrumental earthquake recordings, was introduced by C. F. Richter in 1930.
- Quite recently the seismic moment M_O has been introduced, which is a measure of the earthquake size related to the fundamental parameters of the source process (source area, average displacement, shear modulus of the rocks).

Intensity scales

- The Mercalli scale was introduced by Mercalli in 1902.
- An elaboration of the Mercalli scale, was published by Sieberg in 1923. This form was used by Wood and Neumann, in 1931, as the basis for the Modified Mercalli (MM).
- Subsequently other intensity scales have been introduced by Mercalli, Cancani and Sieberg (MCS) and by Medvedev, Sponeuer and Karnik (MSK).
- More recently the EMS-1992 macroseismic scale has been proposed.

Intensity scales

- The existence of many different scales is a demonstration of the complexity of the problem of describing earthquake effects. The multiplicity of scales generates some problems in practical applications, that must therefore rely upon very conservative assumptions.

Comparison of seismic intensity scales:
MM – Modified Mercalli
RF – Rossi-Forel
JMA – Japanese Meteorological Agency
MCS – Mercalli-Cancani-Sieberg
MSK – Medvedev-Sponheuer-Karnik

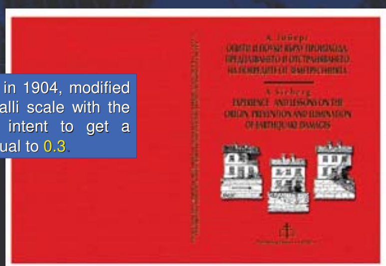
MM	RF	JMA	MCS	MSK
I	I		II	I
II	II	I	III	II
III	III		IV	III
IV	IV, V	II	V	IV
V	VI	III	VI	V
VI	VII	IV	VII	VI
VII	VIII	V	VIII, IX	VII
VIII	IX		X	VIII
IX		VI	XI	IX
X	X		XII	X
XI		VII		XI
XII				XII

Intensity scales

- Intensity provides a qualitative description of the earthquake size, based on the observation of the related damage. Hence, for a given earthquake, the intensity I can be different in different places.
- Intensity values are discrete; undue accuracy in related computations can be misleading.

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

$$\log A = a + bI$$



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

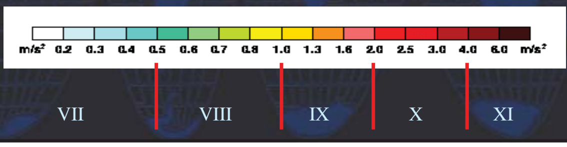
Hence one degree of intensity corresponds to a factor two in the values of ground motion:

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

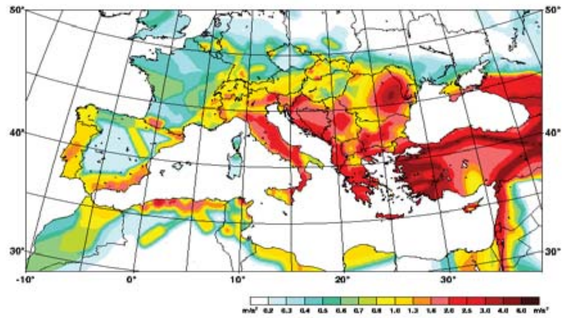
PGV(I)/PGV(I-1)=2

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

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



The GSHAP probabilistic map at 475 years



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

What can we learn from a catalog of earthquakes?

All catalogs have errors, which may render invalid conclusions derived in a study based on a catalog of earthquakes.

Ways to handle with catalog errors:

- Postpone the analysis until the data are revised;
- Perform a comparative analysis among different catalogs, whenever available;
- Use robust methods of analysis, within the limits of their applicability;
- Test the robustness of the obtained results against possible errors in the data set.

Multiscale Approach to Seismic Catalogs Analysis Scales of investigations

Narrow scale

- Small magnitude events
- Temporal evolution of seismicity over short time periods
- Local seismicity patterns

Intermediate scale

- Strong events
- Temporal evolution of seismicity at intermediate-term scale
- Regional seimicity patterns

Large scale

- Largest earthquakes
- Temporal long term evolution of seismicity
- Seismic hazard

area (R~25-50 km)

Local scale good quality instrumental data

- Example: Catalogs of volcanic earthquakes

area (R~ hundreds km)

National scale instrumental data, sporadically integrated with intensity information

- Example: The Updated Catalog of Italy

area (R~ thousands km)

Large scale and long term data, mainly intensity information

Example: Unified catalog for North Africa

Comparing low magnitude local catalogs: Vesuvius and Etna volcanic areas

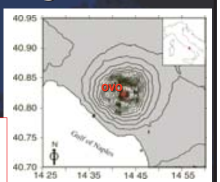
To what extent our the results of our analysis depend on the considered data set?

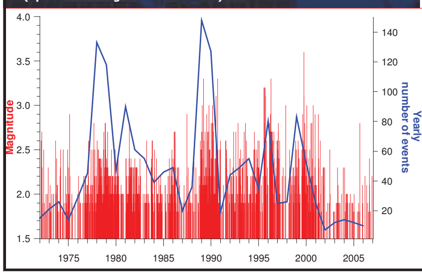
⇒ Compare results from different catalogs

Volcanic earthquakes at Mt. Vesuvius: the OVO earthquake catalog

Data used: catalog of volcanic earthquakes recorded at the station OVO (Osservatorio Vesuviano – INGV, Naples)

Time period: since 1972 (updated catalog available on-line)



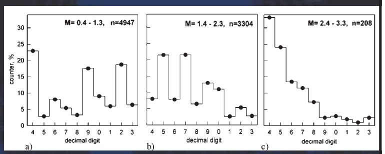


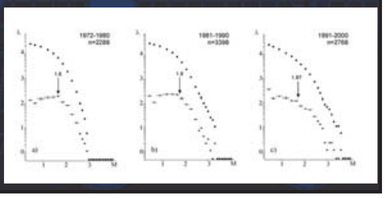
Time sequence of the events M(t) and yearly number of earthquakes with $M \geq M_c = 1.8$ reported in the OVO catalog

The OVO earthquake catalog

Magnitude grouping: The analysis evidences whether there are dominating values of magnitudes. It permits to choose the appropriate intervals of magnitude grouping ΔM to be considered for the frequency-magnitude distribution.

Catalog completeness: The completeness of the catalog is determined from the frequency-magnitude distribution λ(M), where λ is the number of earthquakes within each magnitude grouping interval ΔM, normalized to the space-time-magnitude volume unit V=[1000 km2 x 1 year x 1 M]. $M_{completeness}=M_C=1.8$





Seismic energy release

The seismic energy release is studied considering the quantity *E**, computed from magnitude according to the formula:

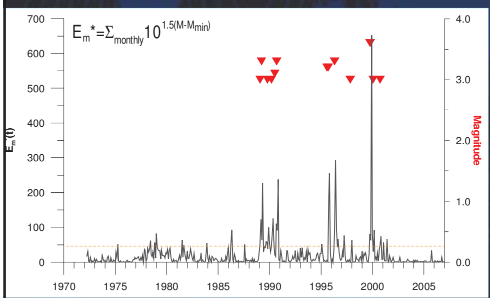
$$E^* = 10^{d(M - M_{\min})} \qquad d = \text{const}$$

*E** represents the energy release normalised to the energy of the minimum magnitude event considered in the analysis, $M_{min}=M_C=1.8$:

$$E^* = \frac{E}{E_{\min}} = \frac{10^{c+dM}}{10^{c+dM_{\min}}} \qquad c,d = \text{const}$$

Seismic energy release

Monthly normalised energy release *E*(t)*
(time windows of one month shifted by one month)

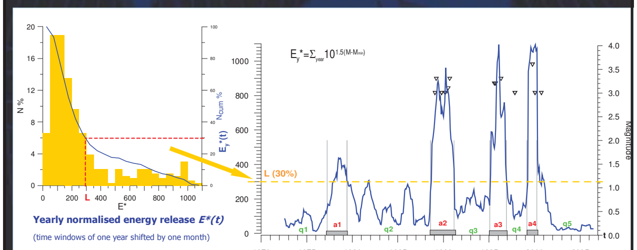


The curve of monthly *E*(t)* exhibits an almost constant background rate ($E^*_{monthly} \leq 50$) during about 90% of the period of observation), with sporadic periods of strongly increased rates

Seismic energy release

Formal definitions of the periods of quiescence, q and of the periods of activity, a.

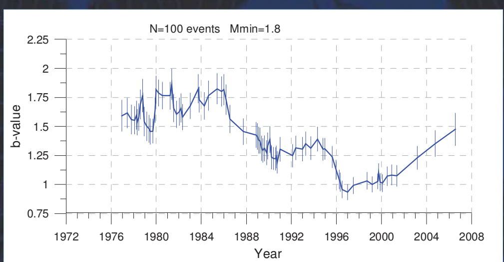
- Periods of high seismic activity are characterised by energy rates with an increasing trend in time. An high number of earthquakes is not necessarily associated with high magnitudes.



De Natale et al. (2004). Pageoph, 161, 1, 123-144

Time changes of the *b-value*

- The estimation of the time variations of the b-value in the Gutenberg-Richter (GR) law, shows that it decreases progressively from 1.8, before 1986, to about 1.0 in 1996. The b-value appears progressively increasing since 2001.



(Maximum likelihood estimation by Wiemer & Zuniga, ZMAP software)

Time changes of the *b-value*

Estimation of the parameter b of the GR law for the formally identified periods of activity and quiescence (*Molchan et al., 1997*).

Interval	Time window	b-value		N
		a-intervals	q-intervals	
q1	1972.02.23-1977.10.31		1.59	143
a1	1977.11.01-1979.05.31	1.56		190
q2	1979.06.01-1988.07.31		1.72	482
a2	1988.08.01-1991.02.28	1.32		307
q3	1991.03.02-1995.01.31		1.29	167
a3	1995.02.01-1996.12.01	0.90		107
q4	1996.12.02-1999.02.28		1.08	62
a4	1999.03.01-2000.06.01	1.03		99
q5	2000.06.02-2007.05.01		1.53	112

De Natale et al. (2004). Pageoph, 161, 123-144

Time changes of the *b-value*

Individual intervals

Comparison of the *b-value* for the formally identified periods of activity and quiescence, as well as for some groups of them (*Molchan et al., 1997*).

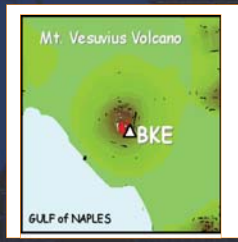
Intervals compared	π%	Conclusion of the comparison
a1, a2, a3, a4	>99.9%	b-values are different
a1, a2	92.6%	the differences in b-values is not significant
a3, a4	61.0%	the differences in b-values is not significant
q1, q2, q3, q4, q5	>99.9%	b-values are different
q1, q2	55.0%	the differences in b-values is not significant
q3, q4, q5	90.6%	the differences in b-values is not significant

Composite intervals

Intervals compared	N	b	b_{min}	b_{max}	Conclusion
a1+a2	497	1.37	1.26	1.49	b-values are different
a3+a4	190	0.96	0.81	1.12	
q1+q2	625	1.69	1.55	1.84	b-values are different
q3+q4+q5	343	1.31	1.17	1.46	
a1+a2+q1+q2	1122	1.51	1.42	1.61	b-values are different
a3+a4+q3+q4+q5	543	1.16	1.06	1.26	

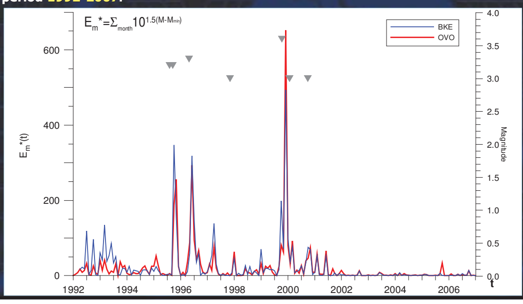
The BKE earthquake catalog

To test the stability and the significance of the time properties of seismicity observed for the OVO catalog, a similar analysis is performed using a different catalog of Vesuvian earthquakes, compiled from the records at the BKE station during the period 1992-2007(*Saraò et al., ICTP report, 2002*).

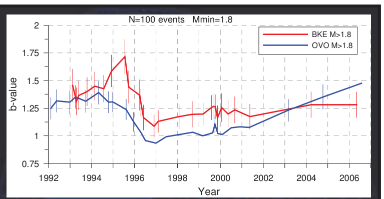


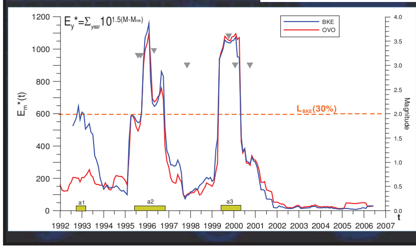
Time changes in seismic activity: comparison with the BKE catalog

The time variations of the b-value and seismic energy release, observed for the OVO catalog, are verified performing a similar analysis with a different catalog of Vesuvian earthquakes, as compiled from the records at the BKE station during the period 1992-2007.



Time changes in seismic activity: comparison with the BKE catalog

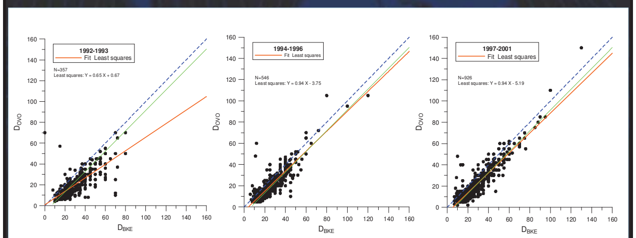




The analysis performed using the catalog compiled for the BKE stations confirms the b-value decrement and the identification of the periods of quiescence and activity, except for the time interval 1992-1994.

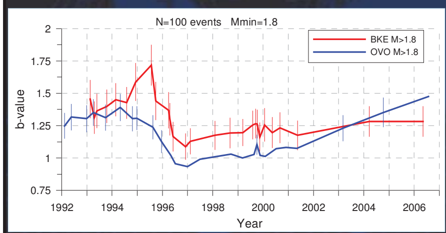
Time changes in seismic activity: comparison with the BKE catalog

The differences observed during the period 1992-1994 are well explained by a certain overestimation of BKE durations during such period of time, as shown by the comparison of OVO and BKE durations for the common events



Problem: identification of the common events in catalogs characterised by low magnitude and highly clustered events

Time changes in seismic activity: the BKE catalog



- **The analysis performed using the catalog compiled for the BKE station confirms the *b-value* decrement till 2000.**
- **The raise of the b-value, observed in the time interval 2001-2006, is statistically significant only for the OVO catalog.**

b-value comparison since 1999 (last periods of activity and quiescence)

Catalogues	π%	Time interval	N	b ± Δb	Conclusion
OVO	99.5%	1999.3.1-2000.6.1	99	1.03±0.22	Difference is significant
		2000.6.2-2007.1.1	110	1.55±0.28	
BKE	35.4%	1999.6.1-2000.5.1	103	1.10±0.24	Difference is NOT significant
		2000.5.2-2007.1.1	129	1.18±0.22	

The catalog of seismic events at Etna Volcano

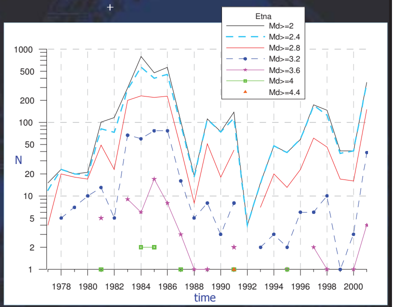
The **ETNA instrumental catalog**

(S. Gresta- INGV_DPC Sub-project V3_6 Etna)

contains 3783 events occurred within the territory surrounding the volcano (Lat. 37.4°-38.0°; Lon. 14.4°-15.4°) in the time interval 1977.11-2001.12.

Max. magnitude M_d = 4.4

ORIGIN TIME		MAGNITUDE	
		OLD	NEW
1982-06-29	23.12	2,8	2,5
1983-05-13	16.41	2,3	2,5
1983-05-14	17.41	3,4	2,6
1984-10-18	5.31	2,7	2,4
1984-11-27	10.05	3,2	2,8
1984-12-20	21.46	2,6	2,4
1984-12-22	21.55	3,6	1,8
1984-12-23	19.53	2,2	1,8
1989-06-22	22.28	4,8	3,0

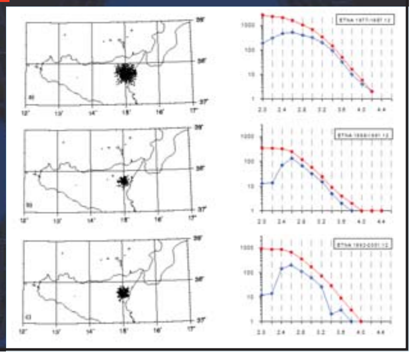


A careful analysis of the instrumental ETNA catalog allowed us evidencing some formal errors in the data=> the magnitude of 9 events has been modified accordingly

The catalog of seismic events at Etna Volcano

Three different time intervals can be distinguished in the Etna catalog:

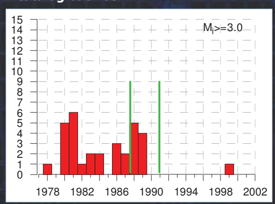
A) 1977.11-1987.12
B) 1988.01-1991.12
C) 1992.01-2001.12



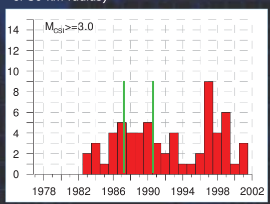
ETNA catalog: comparative analysis

A comparative analysis is performed between the ETNA instrumental *(Sub-project V3_6 - Etna)* and macroseismic *(Azzaro et al., 2000)*[1] catalogs, as well as with the Italian instrumental catalog CSI *(Castello et al., 2006)*[2]

a) Comparison ETNA– Macroseismic catalog: 32 events with $M_I \geq 3.0$ are reported in the macroseismic catalog but not in ETNA



b) Comparison ETNA– CSI catalog: 64 events with $M_{CSI} \geq 3.0$ are reported in the CSI catalog but not in ETNA (within a circle of 30 km radius)



[1] Catalogo macrosismico dei terremoti etnei: www://http.ct.ingv.it/sismologia/macro/default.htm
[2] Catalogo della sismicità italiana CSI versione 1.1: www.ingv.it/CSI

Etna catalog: comparative analysis and integration of data

Among the 32 events ($M_I \geq 3.0$) reported in the macroseismic catalog and not in the instrumental ETNA catalog, 14 events are also reported in CSI (9 of them have $M_{CSI} \geq 3.0$ too)

⇒ Missing events in catalog ETNA are generally due to a gap in the associated instrumental recordings

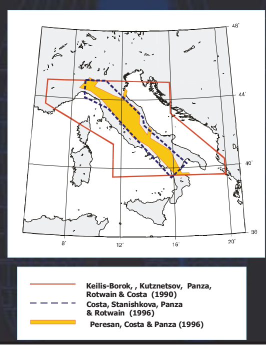
⇒ ETNA catalog has been integrated by incorporating the missing events, as reported either in CSI or macroseismic catalogs, within a circular area (R=30 km, centred in φ = 37.7°; λ = 14.9°)

ORIGIN TIME		LAT	LON	M_{MACRO}	M_{CSI}
17/05/1978	8.57	37.69	15.10	3.2	CSI starts in 1981
21/08/1980	15.57	37.58	15.07	3.2	
22/08/1980	23.28	37.58	15.06	3.2	
23/08/1980	7.52	37.59	15.08	3.4	
16/09/1980	2.30	37.60	15.08	3.4	
26/11/1980	1.38	37.72	15.12	3.4	
08/01/1981	16.36	37.81	15.07	3.4	0
15/02/1981	0.58	37.70	15.12	3.0	
03/07/1981	13.05	37.67	15.14	3.2	4.3
19/07/1981	12.56	37.73	15.15	3.2	
01/09/1981	23.32	37.65	15.15	3.2	
02/09/1981	18.20	37.64	15.16	3.0	
07/07/1982	23.45	37.81	15.07	3.4	
27/03/1983	8.05	37.68	14.91	3.5	
20/07/1983	22.03	37.60	15.10	3.7	4.3
17/06/1984	16.51	37.63	15.14	3.2	0
18/10/1984	11.58	37.81	15.07	3.4	3.9
18/01/1986	21.41	37.70	15.14	3.2	3.6
29/10/1986	23.18	37.81	15.05	3.7	0
04/12/1986	12.50	37.64	15.17	3.2	
06/05/1987	18.20	37.64	14.92	3.2	3.1
13/08/1987	7.22	37.75	15.01	3.2	3.2
01/04/1988	23.43	37.71	15.13	3.4	3.1
17/11/1988	23.51	37.60	15.08	3.0	
20/11/1988	11.10	37.60	15.08	3.0	
21/11/1988	2.19	37.60	15.09	3.4	2.8
21/11/1988	2.59	37.59	15.08	3.0	
15/01/1989	4.00	37.63	15.14	3.0	2.9
29/01/1989	7.30	37.71	15.16	3.7	3.4
07/06/1989	21.51	37.71	15.10	3.0	
11/10/1989	3.19	37.51	15.02	3.0	
05/08/1999	14.57	37.69	14.94	3.2	4

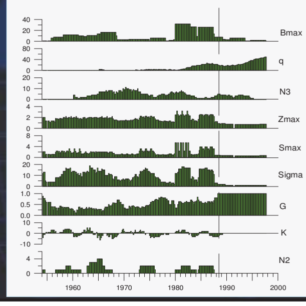
Analysis of earthquake catalogs for earthquake prediction purposes: the case of Italy

Identify systematic long-lasting changes in an earthquake catalog
⇒ Cross-comparison between different available data sets

CN algorithm and long lasting changes in reported magnitudes



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



Magnitude comparison: Central Region

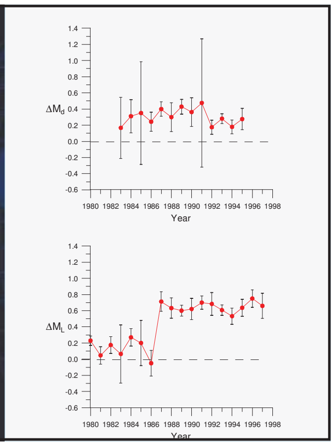
Duration Magnitude

M_d(NEIC)-M_d(ING)
$M_d \geq 3.0$
(1983-1997)
ΔM_d=0.30 0.04
Yearly Average

Yearly Average differences NEIC-ING

Local Magnitude

M_L(NEIC)-M_L(ING)
$M_L \geq 3.0$
(1980-1986)
ΔM_L=0.13±0.05
(1988-1997)
ΔM_L=0.64±0.04
Yearly Average



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

Magnitude comparison: Italian territory

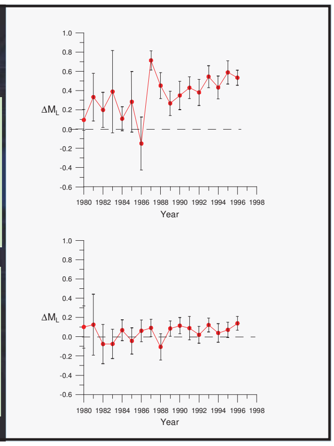
LDG - ING

M_L(LDG)-M_L(ING)
$M_L \geq 3.0$
(1980-1986)
ΔM_L=0.18 0.08
(1988-1996)
ΔM_L=0.44 0.04
Yearly Average

Local Magnitude: Yearly Average differences

NEIC - LDG

M_L(NEIC)-M_L(LDG)
$M_L \geq 3.0$
(1980-1986)
ΔM_L=0.03±0.06
(1988-1996)
ΔM_L=0.08±0.03
Yearly Average

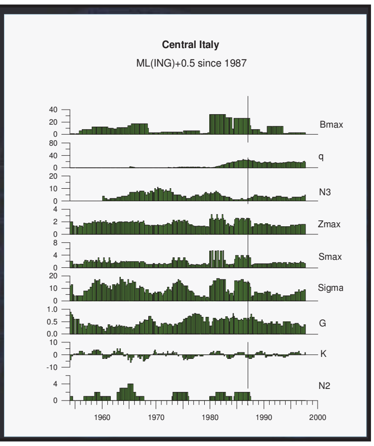


Peresan, Panza, Costa (2000) – GJI, 141, 425-437

CN algorithm and long lasting changes in reported magnitudes

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

M=ML(ING)+0.5



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

Compilation of an updated catalog for CN monitoring in Italy

Databases available to us:

CCI1996: Italian catalog PFG revised+INGV data
Priority: M_L, M_d, M_I

NEIC: PDE Preliminary Determinations of Epicenters from NEIC (global catalog).
Available Magnitude estimates: m_b, M_S, M_1, M_2)
Priority: to be defined

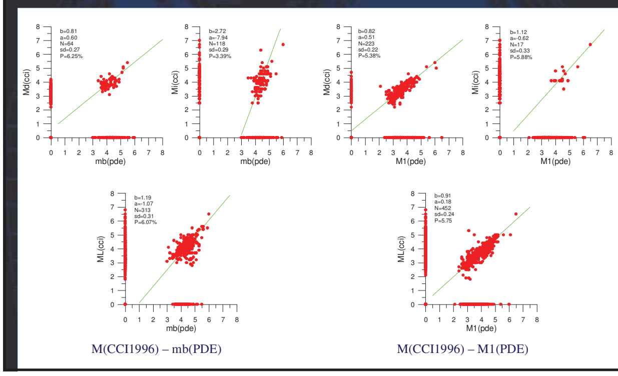
ALPOR: Catalogo delle Alpi Orientali (local catalog for eastern Alps)
Priority: M_L, M_I

Compilation of an updated catalog for CN monitoring in Italy

Procedure:

- **Study of the completeness of PDE catalog;**
- **Study of the relations between different kind of magnitudes reported in the CCI1996 and PDE catalogs;**
- **Formulation of a rule for the selection of magnitude priority in PDE, similar to the priority used for CCI1996;**
- **Construction of the Updated catalog, integrating CCI1996, ALPOR and NEIC data (compatibly with the completeness of NEIC).**

Operating magnitude selection

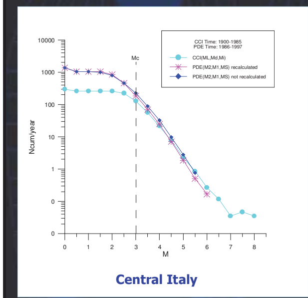


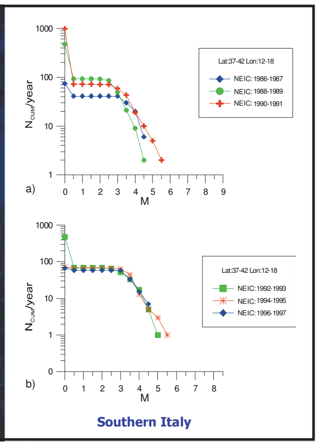
Operating magnitude selection

$$M1(PDE) \longrightarrow M_d(CCI)$$
$$M2(PDE) \longrightarrow M_L(CCI)$$
$$M_S(PDE) \longrightarrow \text{Poor statistic}$$
$$m_b(PDE) \longrightarrow \text{Not representative of any of CCI magnitudes}$$

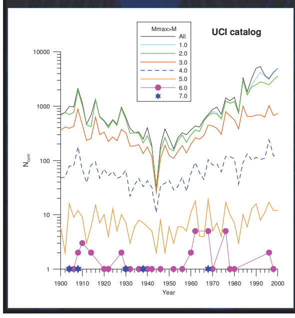
$$M_{CCI}(M_L, M_d, M_I) \Longrightarrow M_{PDE}(M2, M1, M_S)$$

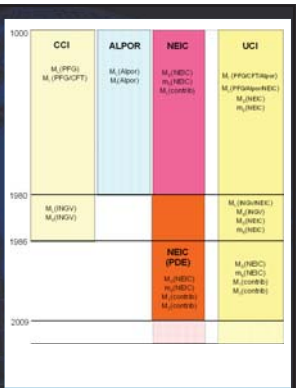
Operating magnitude and data completeness





The Updated Catalog of Italy UCI2001





Current instrumental earthquake catalogs for Italy: are they suitable for the space-time analysis of seismicity?

- Space and time homogeneity of the input earthquake catalogs is a necessary pre-requisite for any reliable characterization of seismic activity in an area;
- Particularly relevant in view of the development and testing of prediction/forecast methods based on the analysis of seismicity.

➡ Comparative analysis of the instrumental seismic data proposed for models development and testing in the framework of the CSEP-TRI*, specifically the earthquake bulletins and catalogs for the Italian territory compiled at INGV since 1981.

*Collaboratory for the Study of Earthquake Predictability (CSEP) - Test Region Italy (TRI)
http://www.cseptesting.org/regions/italy

The earthquake catalogs

The data proposed for CSEP-TRI forecast/prediction models are:

- **CPTI08: 1901-2006**
  "Catalogo Parametrico dei Terremoti Italiani"
  http://www.cseptesting.org/regions/italy;
- **CSI1.1: 1981-2002**
  "Catalogo della Sismicità Italiana";
  http://csi.rm.ingv.it/;

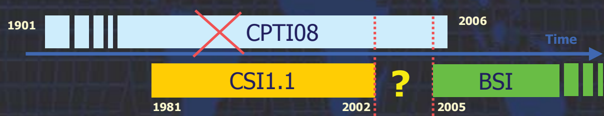
Supplementary data sources

CSEP authoritative data source

- **BSI: since 16 Apr 2005**
  "Bollettino Sismico Italiano"
  http://bollettinosismico.rm.ingv.it/
  http://iside.rm.ingv.it/iside/standard/result.jsp?rst=1&page=EVENTS

The earthquake catalogs

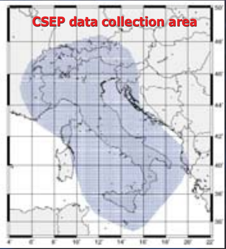
CPTI08 is a **declustered** catalog "with some foreshocks and aftershocks" (*Rovida et al., 2008*); its completeness threshold is **Mc=4.8** (*Christophersen et al. 2009).*
=> not suitable for the analysis of premonitory seismicity patterns, nor for models based on the analysis of seismicity at low magnitude ranges



- **ISIDE: 2003 - April 15, 2005**
  "Italian Seismic Instrumental and parametric Data-basE";
  necessary to fill in the data gap, although it is reported under revision (*Christophersen et al., 2009*) .
  http://bollettinosismico.rm.ingv.it/
  http://csi.rm.ingv.it/;

The analysis

- Analysis of the homogeneity and completeness of the INGV earthquake data (INGV/CSEP catalogs = CSI+ISIDE+BSI) for the period 1981-2009.
- Assessing the consistency among the different INGV/CSEP catalogs.
- Assessing the consistency of INGV/CSEP catalogs with the global catalog NEIC, that is currently used in the real-time earthquake prediction experiment in Italy *(Peresan et al., 2005)* ongoing since more than eight years.

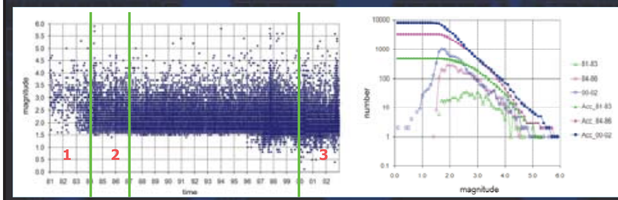


The territory of analysis

CSI1.1 catalog: 1981 - 2002

- **More than 90.000 earthquakes** (about 40.000 with estimated M)
- **A single magnitude assigned to each earthquake**:
  - *ML* estimated from duration (81.9%), 1983-2002;
  - *ML* taken from the CSTI1.0 Catalog (1.6%), 1981-1995;
  - *ML* MedNet (16.2%), 1996-2002;
  - contributed magnitudes, either *mb* or *Mw* (0.3%).

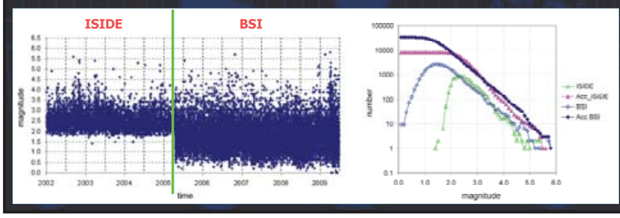
  The proportion of magnitude types is not uniform for small and large earthquakes
- **Completeness varies from Mc=4.0 (1981-1983) to Mc=2.0 (2000-2002)**



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

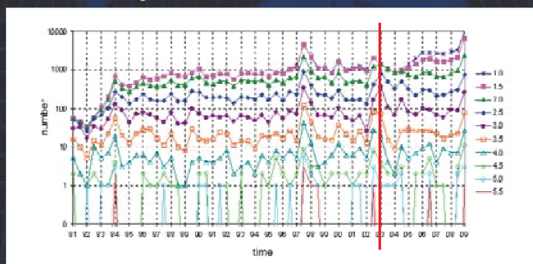
Italian Seismic Bulletin ISIDE +BSI: since 2002

- **ISIDE: 2002- 15 April 2005**
  About 8.000 events. About 98% have *Md* magnitude, while *ML* dominates for M≥4.0
- **BSI: since 15 April 2005**
  About 33.000 events. About 96% have *ML* magnitude; *MD* is mostly given for small earthquakes
- **Completeness varies from Mc=2.5 (ISIDE) to Mc=2.0 (BSI)**



CSI+ISIDE+BSI

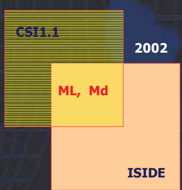
Along with natural variation of seismic activity, one can observe a difference in the average levels of the moderate and small magnitude curves for the periods before and after 2003, that is for CSI1.1 and ISIDE+BSI catalogues.

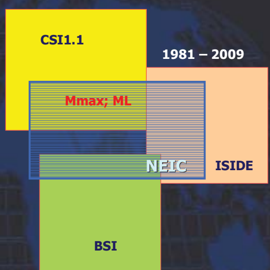


Semi-annual number of earthquakes above different magnitude thresholds

Magnitudes comparison

Equivalent events:
ΔT≤1min
ΔLat≤0.5°, ΔLon≤0.7°



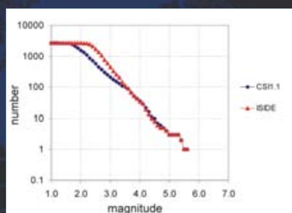


Reference global data set: NEIC
Global Hypocenters Data Base compiled at the US Geological Survey/National Earthquake Information Centre
- It reports contributed *ML*;
- It is used for routine prediction experiment in Italy.

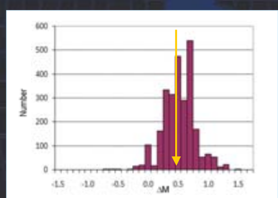
CSI1.1 vs ISIDE: magnitude comparison

Time span: Jan 2002- Dec 2002

The cross-comparison of CSI1.1 and ISIDE bulletin, both available in 2002, evidences that M(CSI) are lower than M(ISIDE), particularly for small events



Frequency-magnitude cumulative distribution for equivalent earthquakes from CSI1.1 and ISIDE

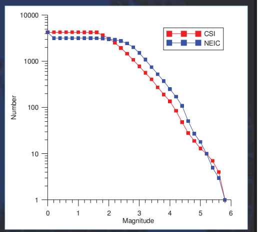


Histogram of magnitude differences for equivalent events M(ISIDE) – M(CSI)

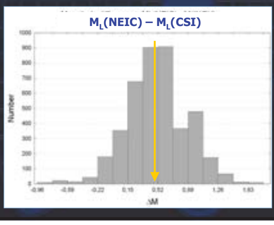
CSI1.1 vs NEIC: Local magnitude comparison

Time span: 1986 - 2002

Focussing on local magnitude estimates, an average M_L(CSI) underestimation of ≈ 0.5 is identified for events with M≥3



Frequency-magnitude cumulative distribution for equivalent earthquakes from CSI and NEIC.

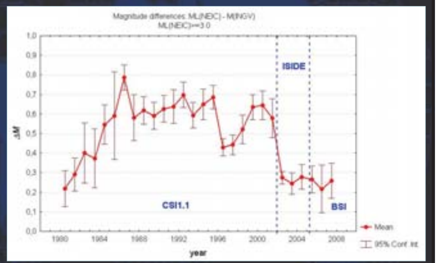


Histogram of local magnitude differences for equivalent events

INGV/CSEP vs NEIC: Local magnitude comparison

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

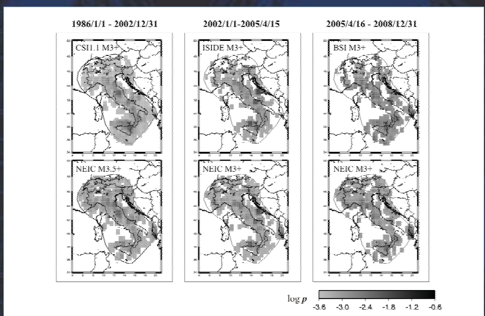
Yearly Average differences M_L(NEIC) – M(INGV) for M_L ≥ 3.0



The relative increase of average differences is well comparable to that evidenced so far by *(Peresan, Panza & Costa, GJI 2000).*

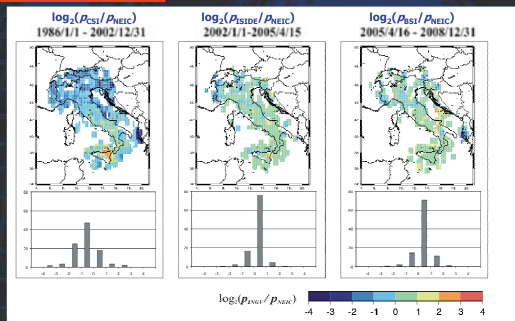
CSI1.1.- Castello, B., et al. (2007). Bull. Seism. Soc. Am. 97(1B): 128-139.

Spatial distribution analysis



Maps of the empirical spatial probability density distribution functions *(pddf)* for earthquake occurrence (3/4°x3/4° cells centred at the grid-points of a 1/4°x1/4° mesh), determined by the INGV/CSEP (first row) and NEIC (second row) data sources.

Spatial distribution analysis



Maps of the ratio of empirical spatial probability density distribution functions 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.

Italian earthquake catalogs are heterogeneous over the last three decades

- **The magnitudes reported in INGV/CSEP catalogs are not uniform. The inconsistency of magnitude is clearly evidenced by the cross-comparison of the CSI1.1 and ISIDE data during the year 2002.**
- **The comparison with global NEIC data confirms the heterogeneity of the INGV/CSEP magnitude estimates over the period 1981 – 2009.**
- **The systematic magnitude underestimation in CSI1.1 catalog in the period 1986-2002, is well comparable to that detected so far (*Peresan et al., 2000*), and confirmed by a later work *(Gasperini et al., 2001).***
- **The analysis evidenced a remarkable spatial heterogeneity of the Italian data in the reporting of earthquakes for the period from 1986 to 2002.**

Toward a Unified Catalog for North Africa

Integrating data from different catalogs

NASG North Africa Seismological Group

UNESCO-IUGS-IGCP Project 457
"Seismic Hazard and Risk Assessment in North Africa"
(Algeria, Libia, Morocco, Tunisia, Egypt, Italy)

North Africa Seismological Group (NASG)

NASG Members & collaborators:

D. Benouar[2], K. Abu Elenean[3], A. Ayadi[6], M. Chourak[8], M. El-Gabry[3], A. Foufa[6], H. Ghazala[10], A. Harbi[6], H. Hussein[3], I. Korrat[10], N. Jabour[5], S. Maouche[6], T. Mourabit[1], G. Panza[7-10], A. Peresan[7-10], A. Ben Suleiman[4], F. Vaccari[7-10], E. Zuccolo[7-10]

1) Abdelmalek Essadi, Faculty of Science & Techniques,Tangiers, **Morocco**
2) University of Bab Ezzouar (USTHB), Fac. of Civil Eng., Univ. of Bab Ezzouar, Alger, **Algeria**
3) National Research Institute of Astronomy and Geophysics, NRIAG, Helwan, Cairo, **Egypt**
4) Al-Fatih University, Tripoli, **Libya**
5) Centre National de Recherche Scientifique et Technique, Rabat, **Morocco**
6) Centre de Recherche en Astronomie, Astrophysique et Géophysique, Algiers, **Algeria**
7) Department of Earth Sciences, University of Trieste, **Italy**
8) Moulay Ismail University, Meknes, **Morocco**.
9) Department of Geology, University of El Mansoura, **Egypt**
10) International Centre for Theoretical Physics, ICTP, Trieste, **Italy**

Toward the compilation of a unified earthquake catalog for North Africa

Aim: **define a procedure for the compilation of a unified and updated earthquake catalog for North Africa, as complete and homogeneous as possible, incorporating information from national catalogs as well as from global data sets.**

Motivation: **Provide basic reliable information for:**

- Space-time analysis of earthquakes occurrence
- Assessment of earthquake hazard and risk
  (e.g. UNESCO-IUGS-IGCP Project 457 - "Seismic Hazard and Risk Assessment in North Africa")
- Intermediate-term middle range earthquake prediction
  (e.g. application of M8 earthquake prediction algorithm – Kossobokov et al. (1999))

The input data

The preliminary national catalogs available to us in the framework of the NASG are:

Morocco: data from CNRST and IS (Morocco) and IGN (Spain).
Time: 1901-2001 *Area:* Lat: 25.4°-38.0°N Lon: -12.7°-0.0°E
(T. Mourrabit, pers.comm.; Ramdani, 1991)

Algeria: data from *Benouar (1993; 1994)*
Time: 1365-1994 *Area:* whole Maghreb region

Tunisia: data from INM (Institut National de Météorologie, Tunisia)
Time: 412-2005 *Area:* Lat: 32.0°-38.0°N Lon: 6.0°-12.0°E
(N. Bouden Romdhane, pers.comm.)

Libya: data from *Suleiman (1995)* and its updates, including information from global datasets ISC, ISS, NEIC
Time: 1907-2005 *Area:* Lat: 20.0°-24.0°N Lon: 9.0°-26.0°E

Egypt: data from *Hussein et al. (2008)*
Time: 1900-2004 *Area:* Lat: 22.0°-33.5°N Lon: 25.0°-36.0°E

Compilation of the unified catalog for North Africa

National catalogs revision and internal homogeneization

- Reappraisal of historical seismicity
- Integration with information from additional sources (nearby networks, global catalogs)
- Checking for formal errors and possible duplicates
- Magnitudes homogeneization

Examples Algeria, Egypt

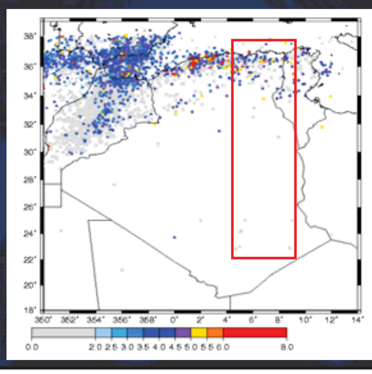
Merging of the different national catalogs into a unified data set

- Standardization of national catalogs format
- Evaluation of time completeness of national catalogs
- Evaluation of space completeness of national catalogs
- Definition of the merging rules
- Merging and preliminary analysis of the unified catalog

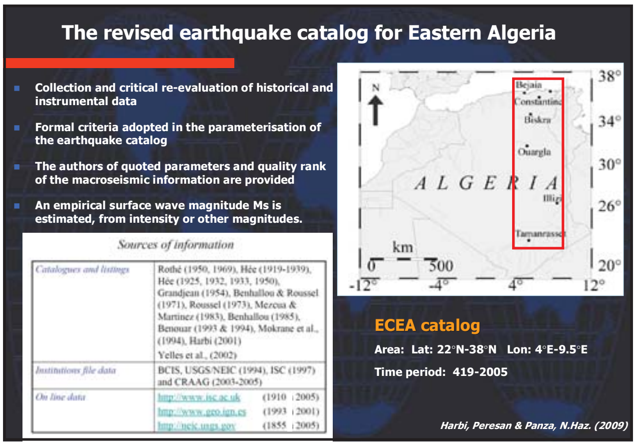
Revision of national earthquake catalogs

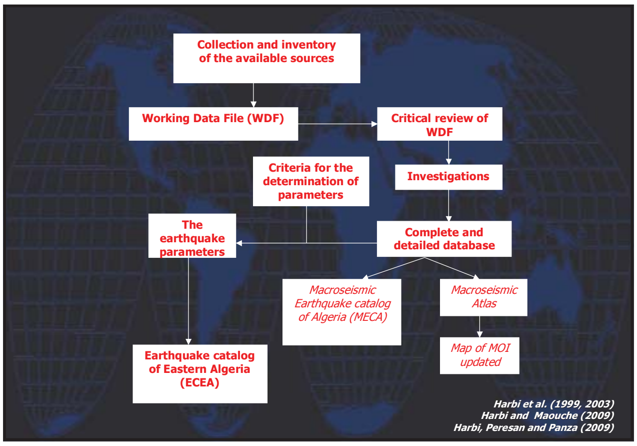
National catalog: Algeria

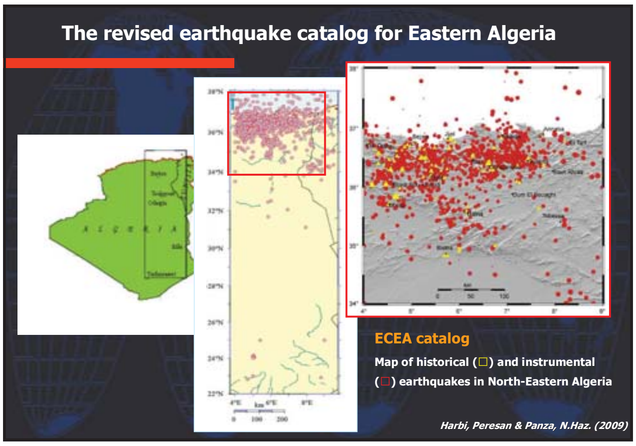
- Time: reports earthquakes since year 1365
- Space: it covers the Algerian territory and most of its neighbouring countries
- Heterogeneous magnitudes and intensity types

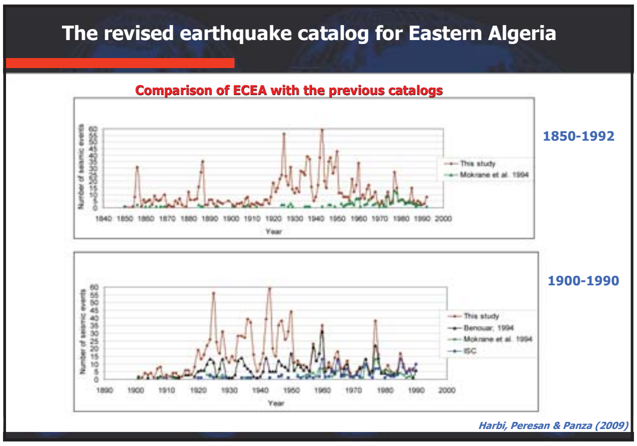


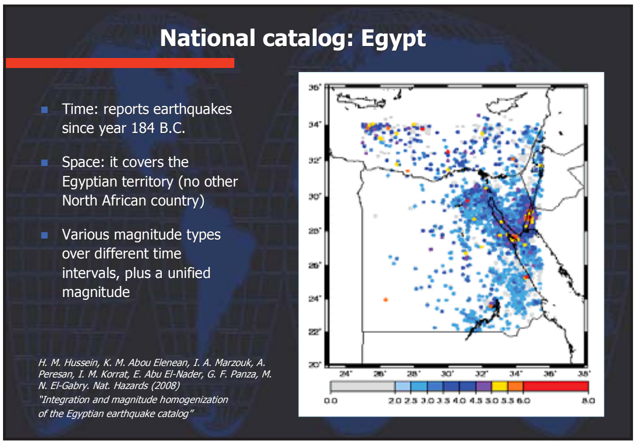
Benouar (1993; 1994)

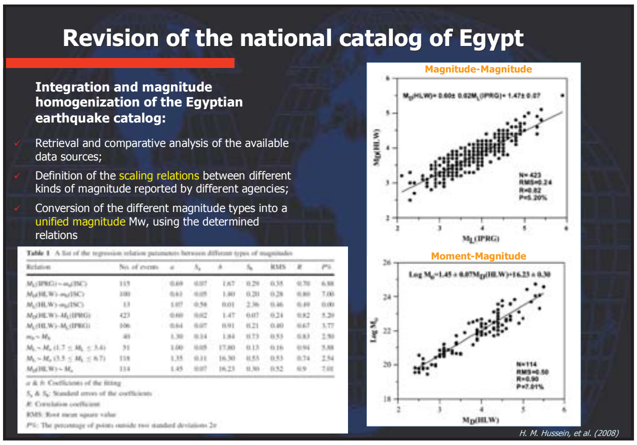

The revised earthquake catalog for Eastern Algeria
Collection and critical re-evaluation of historical and instrumental data
Formal criteria adopted in the parameterisation of the earthquake catalog
The authors of quoted parameters and quality rank of the macroseismic information are provided
An empirical surface wave magnitude Ms is estimated, from intensity or other magnitudes.
Sources of information
Catalogues and listings
Rothé (1950, 1969), Hée (1919-1939), Hée (1925, 1932, 1933, 1950), Grandjean (1954), Benhallou & Roussel (1971), Roussel (1973), Mezcua & Martinez (1983), Benhallou (1985), Benouar (1993 & 1994), Mokrane et al., (1994), Harbi (2001)
Yelles et al., (2002)
Institutions file data
BCIS, USGS/NEIC (1994), ISC (1997) and CRAAG (2003-2005)
On line data
http://www.isc.ac.uk (1910 : 2005)
http://www.geo.ign.es (1993 : 2001)
http://neic.usgs.gov (1855 : 2005)
ALGERIA
ECEA catalog
Area: Lat: 22°N-38°N Lon: 4°E-9.5°E
Time period: 419-2005
Harbi, Peresan & Panza, N.Haz. (2009)


Collection and inventory of the available sources
Working Data File (WDF)
Critical review of WDF
Criteria for the determination of parameters
Investigations
The earthquake parameters
Complete and detailed database
Macroseismic Earthquake catalog of Algeria (MECA)
Macroseismic Atlas
Map of MOI updated
Earthquake catalog of Eastern Algeria (ECEA)
Harbi et al. (1999, 2003)
Harbi and Maouche (2009)
Harbi, Peresan and Panza (2009)

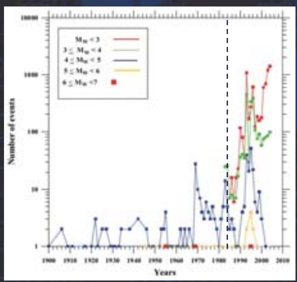

The revised earthquake catalog for Eastern Algeria
ECEA catalog
Map of historical (□) and instrumental (□) earthquakes in North-Eastern Algeria
Harbi, Peresan & Panza, N.Haz. (2009)


The revised earthquake catalog for Eastern Algeria
Comparison of ECEA with the previous catalogs
1850-1992
1900-1990
Number of seismic events
Year
This study
Mokrane et al. 1994
Benouar, 1994
ISC
Harbi, Peresan & Panza (2009)

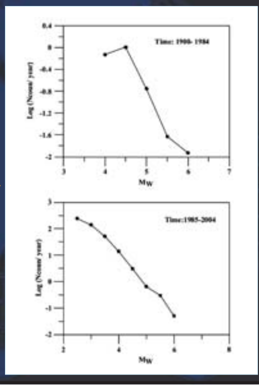

National catalog: Egypt
Time: reports earthquakes since year 184 B.C.
Space: it covers the Egyptian territory (no other North African country)
Various magnitude types over different time intervals, plus a unified magnitude
H. M. Hussein, K. M. Abou Elenean, I. A. Marzouk, A. Peresan, I. M. Korrat, E. Abu El-Nader, G. F. Panza, M. N. El-Gabry. Nat. Hazards (2008)
"Integration and magnitude homogenization of the Egyptian earthquake catalog"


Revision of the national catalog of Egypt
Integration and magnitude homogenization of the Egyptian earthquake catalog:
Retrieval and comparative analysis of the available data sources;
Definition of the scaling relations between different kinds of magnitude reported by different agencies;
Conversion of the different magnitude types into a unified magnitude Mw, using the determined relations
Magnitude-Magnitude
Moment-Magnitude
H. M. Hussein, et al. (2008)

Revision of the national catalog of Egypt



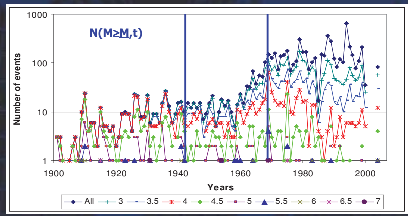
Yearly number of events in the revised catalog as a function of time and moment magnitude

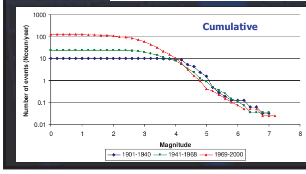


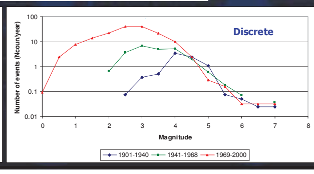
Normalized Frequency-Magnitude relationships

H. M. Hussein, et al. (2008)

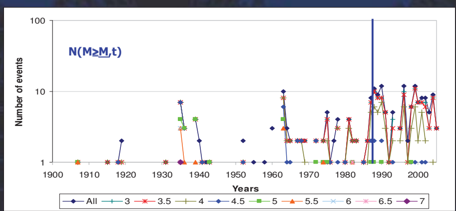
Time completeness: Morocco catalog

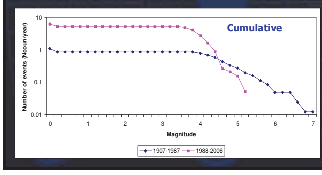


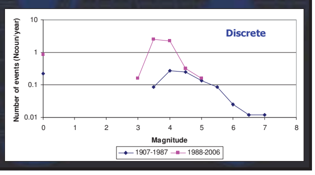




Time completeness: Libya catalog







Spatial completeness data analysis

Spatial completeness is evaluated according to the method proposed by *Kossobokov et. al. (1999).*

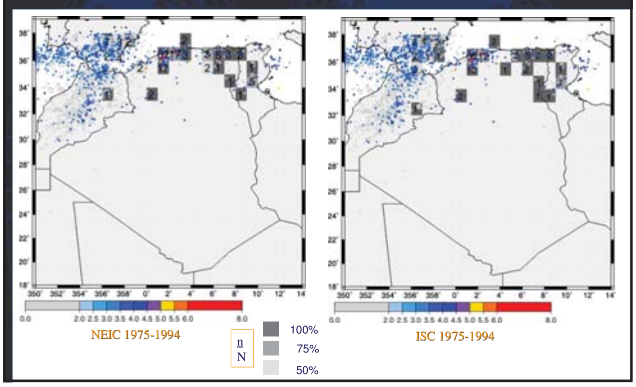
- **Reference test sets: global catalogs NEIC and ISC Earthquakes with M ≥ 4.0, during the period:**
  - ✓ 1975 to 2007 – NEIC
  - ✓ 1975 to 2001 – ISC
- **The corresponding common events are selected from the national catalog:**
  - ✓ ΔTIME ≤ 1 minute
  - ✓ ΔLONGITUDE = 0.5° ; ΔLATITUDE =0.7 °
  - ✓ no limitation on depth and magnitude
- **The study region is divided into cells of 1° X1 ° and for each cell we compute the ratio:** $\frac{n}{N}$

N: total number of NEIC (or ISC) earthquakes inside the cell

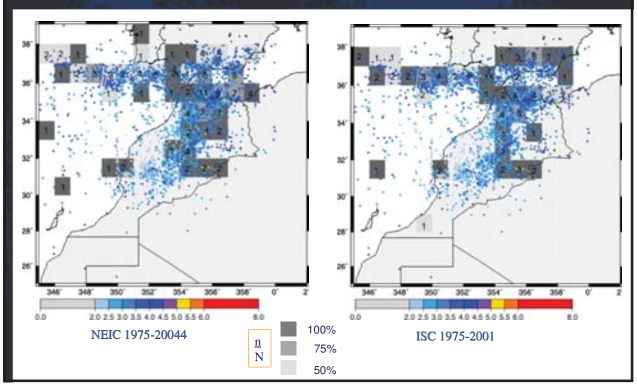
n: number of common events in NEIC (or ISC) and national catalogs

This ratio characterizes the completeness of a national catalog in a given cell

Spatial completeness: Algeria catalog



Spatial completeness: Morocco catalog



The merging procedure

Catalogs merging is performed considering different areas and time intervals, which are found characterized by diverse data properties.

- Each national catalog is assigned a code, so as to be able to identify events from different national catalogs.
- A data priority is defined, based on the preliminary analysis:
  - ✓ National catalog within its political borders
  - ✓ Egypt and Morocco – 1st level
  - ✓ Tunisia and Algeria – 2nd level
  - ✓ Libya – 3rd level
- Three time intervals are considered in the merging procedure: pre-1900, 1900-1965, 1965-1994

Catalogs merging: before 1900

- Available information from national catalogs:
  - Algeria – from 1365 AD
  - Tunisia – from 412 AD
  - Egypt – from 184 BC
- Total number of reported earthquakes: 158
- Rules for identification of common events:
  - ✓ ΔTIME ≤ 1 day
  - ✓ ΔLONGITUDE ≤ 2°, ΔLATITUDE ≤ 2°
  - ✓ ΔDEPTH = not limited
  - ✓ ΔMAGNITUDE = not limited
- Possibly duplicated events: None

Catalogs merging: 1900-1965

- Available information: all of the five national catalogs
- Rules for identification of common events:
  - ✓ ΔTIME ≤ 1 h
  - ✓ ΔLONGITUDE ≤ 1°, ΔLATITUDE ≤ 1°
  - ✓ ΔDEPTH = not limited
  - ✓ ΔMAGNITUDE = not limited
- Total number of common events : 587
  - ✓ 34% - have zero magnitude in Algeria catalog
  - ✓ 96% - of common events are in Morocco territory
  - ✓ 4% - either in Mediterranean Sea or in Spain
- Rule for reporting of common events:
  - All common events between Algeria and Morocco catalog are removed from Algeria catalog
  - All common events between Algeria and Tunisia catalogs are removed from Algeria catalog
- Total number of reported earthquakes: 2774
- Possibly duplicated events: 43

Catalogs merging: 1966-1994

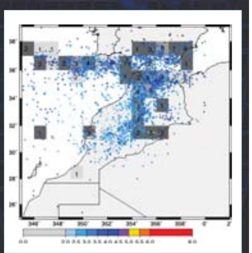
- Available information: all of the five national catalogs
  - ✓ The Egypt catalog follows its national borders;
  - ✓ The Libya catalog slightly extends outside the national borders;
  - ✓ The Tunisia catalog is well self-bounded on the western border and slightly extends into Libya;
  - ✓ The Algerian catalog is characterised by much overlapping with other countries (Morocco and Tunisia)

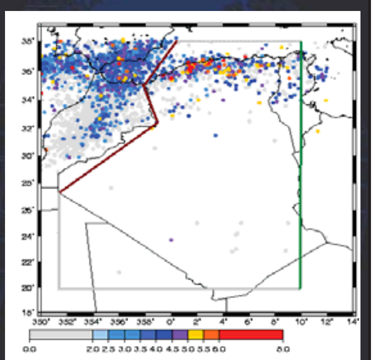
⇒ Need for a clearcut boundary so as to separate the Algeria from Morocco and Tunisia preference territories

- Rules for identification of common events:
  - ✓ ΔTIME ≤ 1 min
  - ✓ ΔLONGITUDE ≤ 1°, ΔLATITUDE ≤ 1°
  - ✓ ΔDEPTH = not limited
  - ✓ ΔMAGNITUDE = not limited

Catalogs merging: 1966-1994

- Procedure: define territory of preference for national catalogs (i.e. polygons for Algeria and Morocco areas) based on completeness analysis





Catalogs merging: 1966-1994

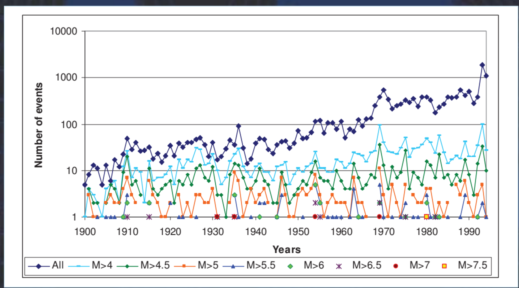
Algeria – Morocco

- Almost all of the 2079 common events are earthquakes located in the Morocco territory and reported by Algeria catalog. Morocco catalog reports only one of the events occurred in Algeria territory
- Rule for reporting of common events:
  - All common events between Algeria and Morocco catalog within Morocco territory are removed from Algeria catalog
  - All common events between Algeria and Morocco catalog within Algeria territory are removed from Morocco catalog

Algeria – Tunisia

- Algeria catalog is partially complete over Tunisia territory
- Rule for reporting of common events:
  - All common events between Algeria and Tunisia catalogs within Tunisia territory are removed from Algeria catalog – 33 events
  - All common events between Algeria and Tunisia catalog reported within Algeria polygon with zero magnitude are removed from Tunisia catalog – 21 events

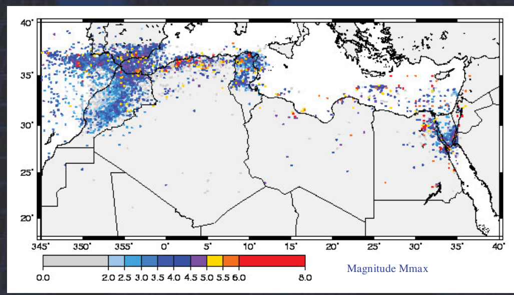
The unified earthquake catalog for North Africa



North Africa catalog time completeness data analysis: 1900-1994

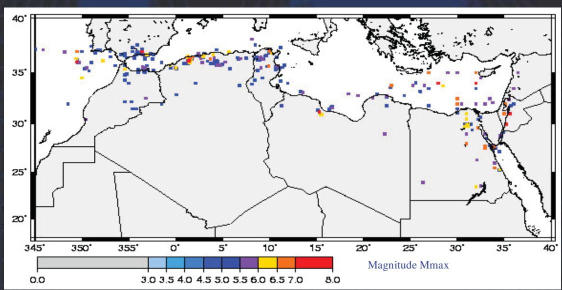
Total number of events: 11635

The unified earthquake catalog for North Africa



All earthquakes reported in the unified catalog over the time period 184 B.C.-1994

The unified earthquake catalog for North Africa



All earthquakes with magnitude Mmax≥5.0 reported in the unified catalog
Time period: 184 B.C.-1994

Next steps…

- **Improvement of the historical seismicity information for the considered NASG countries, incorporating results from progressively available studies**
- **Comparative analysis of magnitudes from different national catalogs**
- **Definition of an operating magnitude estimate, as homogeneous as possible, for the unified catalog**
- **Updating the unified catalog, eventually by making use of global data sets (e.g. NEIC)**

"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."

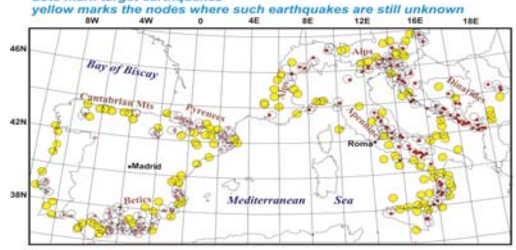
(IAEA – ICTP "Workshop on the Conduct of Seismic Hazard Analyses for Critical Facilities"
Trieste, May 2006)

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

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

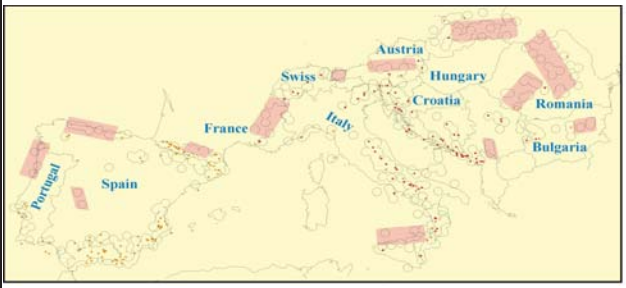
Target magnitudes: $M \geq 6.0$ - Alps, Apennines and Dinarides
$M \geq 5.0$ - Iberia

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



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

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



Conclusions

- Historical information is qualitative and even instrumental data are unavoidably affected by errors. Therefore robust methods of analysis should be used, within the limits of their applicability.
- Special care should be paid to verify data quality and homogeneity and the significance and stability of the obtained results should be evaluated.

Conclusions

- Statistical characterization of earthquake occurrence requires a large amount of homogeneous and complete data, over a long enough time interval. Detailed studies on individual earthquakes are essential but may be not sufficient to characterise earthquake recurrence.
- Information from data different than the seismological ones (morphological, geological, etc.) can be very useful to integrate the data base for seismic hazard analysis, provided the information is collected as much systematically and homogeneously as possible.