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Earthquake Catalogs Analysis: Examples from Different Data Sets

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CN algorithm and long-lasting changes in reported magnitudes: the case of Italy

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SUMMARY

Prediction methods based on seismic precursors, and hence assuming that catalogues contain the necessary information to predict earthquakes, are sometimes criticised for their sensitivity to the unavoidable catalogue errors and possible undeclared variations in the evaluation of reported magnitudes. We consider a real example and we discuss the effect, on CN predictions, of a long-lasting underestimation of the reported magnitudes.

Starting approximately in 1988, the CN functions in Central Italy evidence an anomalous behaviour, not associated with TIPs, that indicates an unusual absence of moderate events. To investigate this phenomenon, the magnitudes given in the catalogue used, which since 1980 is defined by the ING bulletins, are compared to the magnitudes reported by the global catalogue NEIC (National Earthquake Information Centre, USGS, USA) and by the regional LDG bulletins issued at the Laboratoire de Detection et de Geophysique, Bruyeres-le-Chatel, France.

The comparison is performed between the ING bulletins and the NEIC catalogue, considering the local, M_L, and duration, M_d, magnitudes, first within the Central region, and then extended to the whole Italian territory. To check the consistency of the conclusions drawn from ING and NEIC data, the comparison of local magnitudes is extended to a third data set, the LDG bulletins.

The differences between duration magnitudes M_d that are reported by ING and NEIC since 1983 appear quite constant with time. Starting in 1987, an average underestimation of about 0.5 can be attributed to M_L reported by ING for the Central region; this difference decreases to about 0.2 when the whole Italian territory is considered. The anomalous behaviour of the CN functions disappears if a magnitude correction of +0.5 is applied to M_L reported in the ING bulletins. However, such a simple magnitude shift cannot restore the real features of the seismic flow, and ING bulletins are not suitable for CN algorithm application.

Key words: earthquake catalogues, earthquake prediction, Italy, regionalization.

INTRODUCTION

CN is an intermediate-term earthquake prediction algorithm based on the quantitative analysis of premonitory phenomena, which can be detected in the seismic flow preceding the occurrence of strong earthquakes (Gabrielov *et al.* 1986; Keilis-Borok & Rotwain 1990). The quantification of the properties of the seismic flow is performed by means of a set of functions of time (Table 1), which evaluate variations in the seismic activity, seismic quiescence and space–time clustering of events. The normalization of the functions allows us to apply CN to regions with different seismic activity (Keilis-Borok 1996; Rotwain & Novikova 1999).

The CN algorithm has been applied to the monitoring of seismicity in Central Italy since 1990 (Keilis-Borok *et al.* 1990; Costa *et al.* 1996; Peresan *et al.* 1998a). The analysis of the time behaviour of CN functions for the different regionalizations defined for Central Italy (Fig. 1) allowed us to observe the common anomalous flat values of some functions (see Z_{max}, S_{max}, Sigma, K and G in Fig. 2), starting approximately in 1988. The flat trend of the functions, never observed before, indicates the absence of moderate events and hence evidences an unusual decrease in the seismicity rate, suggesting the need to check for possible changes in the magnitudes reported by the catalogue used.

Until July 1997 the catalogue used for CN monitoring in Italy was the CCI1996 (Peresan *et al.* 1997). This catalogue is composed of the revised PFG catalogue (Postpischl 1985) for the period 1000–1979, and since 1980 we have updated it with the bulletins distributed by the Istituto Nazionale di

Table 1. Definition of the time functions used in the CN algorithm for the quantification of the properties of the seismic flow (from Keilis-Borok *et al.* 1990). The magnitude thresholds m_1, m_2, m_3 that allow the normalization of the functions are fixed according to the average yearly frequency of the main shocks that occurred within the region during the learning period (1954–1986). For the Central region (in dark grey in Fig. 1) $m_1 = 4.2$, $m_2 = 4.5$, $m_3 = 5.0$, corresponding to the standard yearly average frequencies $n_1 = 3.0$, $n_2 = 1.4$, $n_3 = 0.4$.

$N_2(t)$	Number of main shocks with $M \geq m_3$ that occurred in the time interval $(t-3\ \mathrm{yr}, t)$.
$K(t)$	$K(t) = K_1 - K_2$, where K_i is the number of main shocks with $M_i \geq m_1$ and origin time $(t-2j\ \mathrm{yr}) \leq t_i \leq [t-2(j-1)\ \mathrm{yr}]$.
$G(t)$	$G(t) = 1 - P$, where P is the ratio between the number of the main shocks with $M_j \geq m_2 (m_2 > m_1)$ and the number of the main shocks with $M_j \geq m_1$. Only main shocks with origin time t_j in the interval $(t-1\ \mathrm{yr}) \leq t_j \leq t$ are considered.
Sigma(t)	Sigma$(t) = \Sigma\, 10^{\beta(M_i - \alpha)}$; the main shocks with $m_1 \leq M_i \leq M_0 - 0.1$ and origin time $(t-3\ \mathrm{years}) \leq t_i \leq t$ are included in the summation; $\alpha = 4.5$, $\beta = 1.00$.
$S_{\max}(t)$	$S_{\max}(t) = \max\{S_1/N_1, S_2/N_2, S_3/N_3\}$, where S_j is calculated as Sigma(t) for the events with origin time $(t - j\ \mathrm{yr}) \leq t_i \leq [t-(j-1)\ \mathrm{years}]$, and N_j is the number of earthquakes in the sum.
$Z_{\max}(t)$	$Z_{\max}(t) = \max\{Z_1/N_1^{2/3}, Z_2/N_2^{2/3}, Z_3/N_3^{2/3}\}$, where Z_j is calculated as S_j, but with $\beta = 0.5$ and N_j is the number of earthquakes in the sum.
$N_3(t)$	Number of main shocks with $M \geq m_2$, which occurred in the time interval (t-10 years, t-7 years)
$q(t)$	$q(t) = \Sigma_{j=1}^{6} \max\{0{,}6a_2 - n_j\}$, where a_2 is the average annual number of main shocks with $M_j \geq m_2$, n_j is the number of main shocks with $M_j \geq m_2$ and origin time $[t-(8+j)\ \mathrm{yr}] \leq t_i \leq [t-(2+j)\ \mathrm{yr}]$.
$B_{\max}(t)$	Maximum number of aftershocks for each main shock counted within a radius of 50 km for the first 2 days after the main shock.

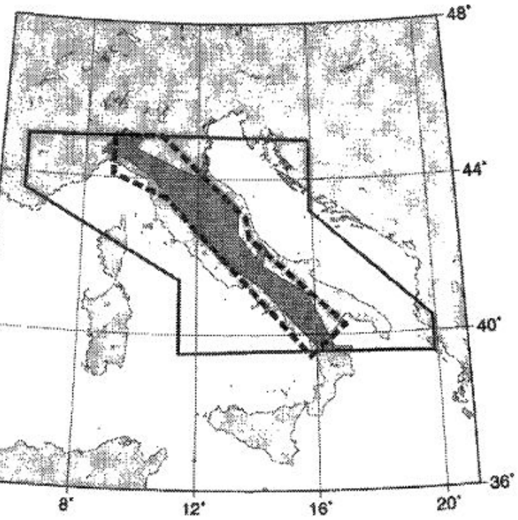


Figure 1. Different regionalizations defined for CN application to Central Italy. The continuous line delimits the region defined by Keilis-Borok *et al.* (1990), while the dotted line shows the region proposed by Costa *et al.* (1995). The region currently used for CN monitoring, defined strictly following the seismotectonic model (Peresan *et al.* 1998a), corresponds to the dark grey area.

Geofisica (ING). For the years 1980–1985 we use the ING paper bulletins, while from 1986 the upgrading is performed with the digital ING bulletins made available via ftp until July 1997. In order to check a possible change in reported magnitudes, the ING data are compared with the following catalogues (Table 2):

the Preliminary Determinations of Epicentres (PDE) distributed by NEIC, USGS, for the time period 1980–1997;

the Bulletins compiled at the Laboratoire de Detection et de Geophysique (CEA, Bruyeres-le-Chatel, France), referred to as LDG in the following, from January 1980 to December 1996.

We do not use the ISC catalogue since it does not provide revised M_L and M_d.

Table 2. Data set used for the catalogue comparison. For each agency the following are indicated: the period of time, the kind of catalogue and how the data are made available.

ING: Istituto Nazionale di Geofisica		
1980–1984	Revised ING bulletins	printed
1985–1986	Digital ING bulletins	floppy disk
1987–1997	Digital ING bulletins	ftp
LDG: Laboratoire de Detection et de Geophysique		
1980–1996	LDG Bulletins	Auto DRM
NEIC: National Earthquake Information Centre, USGS		
1980–1989	Global Hypocentres Data Base	cd-rom
1990–1997	Earthquake Hypocentres Data Files	ftp

The ING bulletins contain two estimations of magnitude: the local magnitude M_L and, since 1983, the duration magnitude M_d. The NEIC global catalogue reports the magnitudes m_b and M_S, both computed by NEIC, plus two values, $M1$ and $M2$, that correspond to magnitudes of a different kind contributed by different agencies. From a previous analysis of the NEIC catalogue (Peresan & Rotwain 1998) we observed that, for the Italian area, both $M1$ and $M2$ are mainly M_d and M_L, and that M_L is 10 times more frequent than M_d. Furthermore, ING is among the contributors to the PDE, and it supplied information for more than 600 events, from 1987 to 1997, as can be observed by listing the events with network code ROM reported in the PDE catalogue. Most of these events have magnitudes below 4.0, especially when M_d is considered, while about 100 of them have $M_L > 4.0$. The bulletins distributed by LDG contain two magnitude values, mainly corresponding to M_L and M_d.

In order to perform the magnitude comparison, the events common to the different catalogues are identified according to the following rules: (a) time difference $\Delta t \leq 1$ min; (b) epicentral distance $\Delta\mathrm{Lat} = \Delta\mathrm{Lon} \leq 1°$ for the comparison with the global catalogue (Storchak *et al.* 1998). No limitation is imposed on magnitude or depth differences.

The analysis is performed by evaluating, for a fixed type of magnitude, the quantities

$$\Delta M = M(\mathrm{C1}) - M(\mathrm{C2}), \tag{1}$$

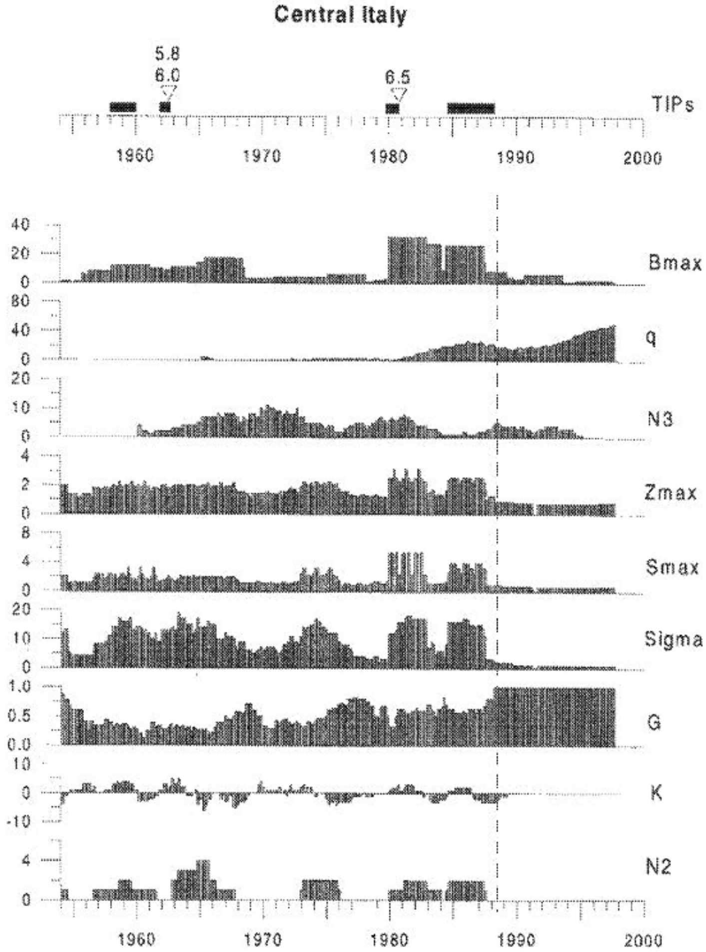


Figure 2. Time diagrams of the standard CN functions obtained for the Central region shown in Fig. 1. Functions Sigma, S_{max} and Z_{max} are evaluated for $4.2 \le M \le 4.6$, functions K, G, N_3, q for $M \ge 4.5$ and function N_2 for $M \ge 5.0$; magnitude thresholds have been selected according to the general rules for normalization of functions (Keilis-Borok & Rotwain 1990). The corresponding diagram of TIPs (times of increased probabilities) obtained using the CCI1996 catalogue is given at the top of the figure (triangles indicate the occurrence of strong events). The dotted line indicates the beginning of the anomalous behaviour of functions.

which are the differences between magnitudes of the same type reported in the catalogues C1 and C2 for each of the common earthquakes.

The comparison between ING and NEIC estimations is performed considering M_L and M_d separately among the events for which M_L and M_d are reported in both the catalogues. The events contributed to NEIC by ING, which represent a relatively small fraction of the set of common events (less than 10 per cent), are obviously excluded from the analysis. Initially, the comparison is focused on the Central region (Fig. 1) and the yearly average values ΔM_L and ΔM_d are evaluated from the common events contained in the area monitored using the CN algorithm. Subsequently, the comparison between the ING and NEIC catalogues is enlarged to the whole Italian territory and its surroundings, as shown in Fig. 9.

To check the consistency of the conclusions drawn from ING and NEIC data, the comparison of M_L is extended to a third catalogue, and the ING and NEIC M_L are compared directly with the M_L reported by the LDG bulletins. Since the LDG is among the NEIC contributors for the area analysed, the NEIC events with magnitude code LDG are obviously excluded when performing the comparison between LDG and NEIC data.

CHANGES IN REPORTED MAGNITUDES FOR CENTRAL ITALY

The analysis of the behaviour of CN functions in Central Italy allows us to identify the anomalous flat trend of some of the functions (Fig. 2), starting approximately in 1988. Such a flat trend indicates an unusual absence of moderate events.

To look for an explanation for this anomaly we focus our attention on the magnitude variations within the Central region currently used for the monitoring of seismicity (in dark grey in Fig. 1). The subcatalogue of earthquakes common to ING and NEIC contains about 800 events. The operating magnitude for CN monitoring is chosen from the Italian catalogue CCI1996, and hence from ING bulletins, according to the priority order M_L, M_d (Costa *et al.* 1996; Peresan *et al.* 1998a); therefore, local magnitudes play a relevant role in the CN analysis of seismicity. Hence, as a first stage, we study the discrepancies among the M_L values reported in the two catalogues, i.e. the quantity

$$\Delta M_L = M_L(\text{NEIC}) - M_L(\text{ING}). \tag{2}$$

The histograms of ΔM_L are plotted for three contiguous ranges of magnitude (Fig. 3), chosen to correspond to the CN magnitude thresholds for Central Italy. The events with $M_L < 3$ are not used by CN, the events with $3.0 \le M_L < 4.2$ are included only in the counting of aftershocks, and those with $M_L \ge 4.2$ can enter into the calculation of functions. For most of the events, $\Delta M_L > 0$, while a secondary peak around $\Delta M_L = 0$ can be seen in Fig. 3 for the smaller events.

In order to detect a possible undeclared long-lasting change in the estimation of the reported M_L, the time behaviour of the yearly average of ΔM_L is analysed considering only earthquakes with $M_L(\text{NEIC}) \ge 3.0$. The yearly number of such events is around 20–25, with two exceptions: there were 83 earthquakes in 1980 (mainly associated with the Irpinia event of 1980 November 23) and only four events in 1987.

The time distribution of ΔM_L yearly averages, shown in Fig. 4(a), indicates the presence of a major discontinuity in 1987. The average ΔM_L, estimated using eq. (2) for two

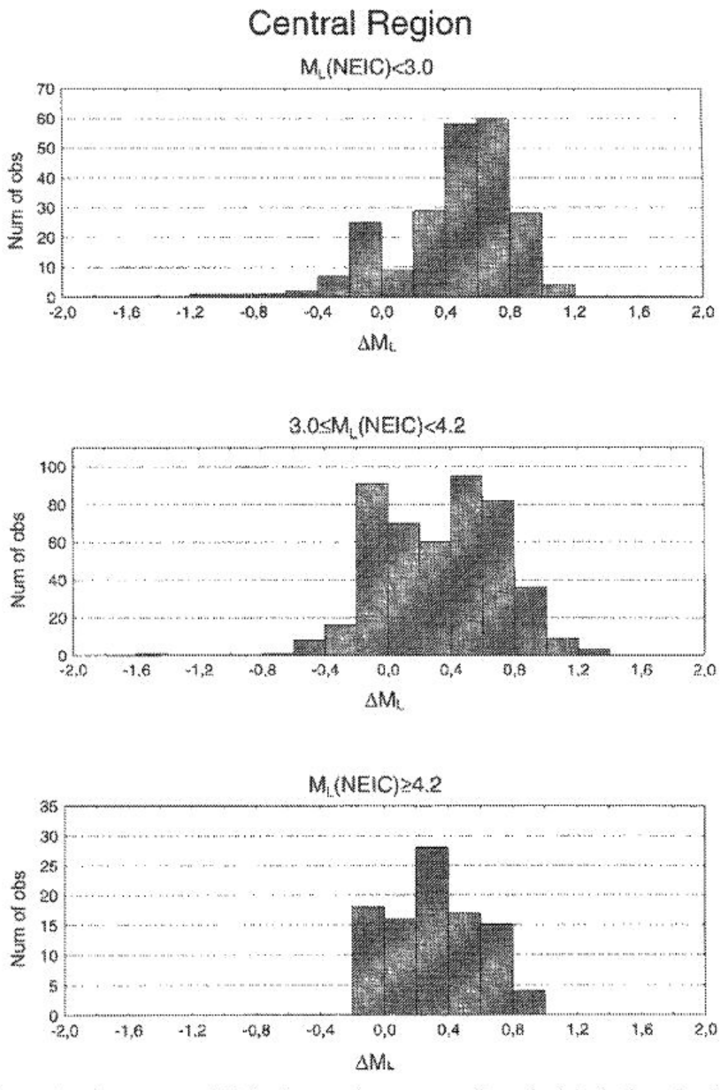


Figure 3. Histograms of the number of events versus ΔM_L for three contiguous ranges of magnitude in the Central region (dark grey area in Fig. 1).

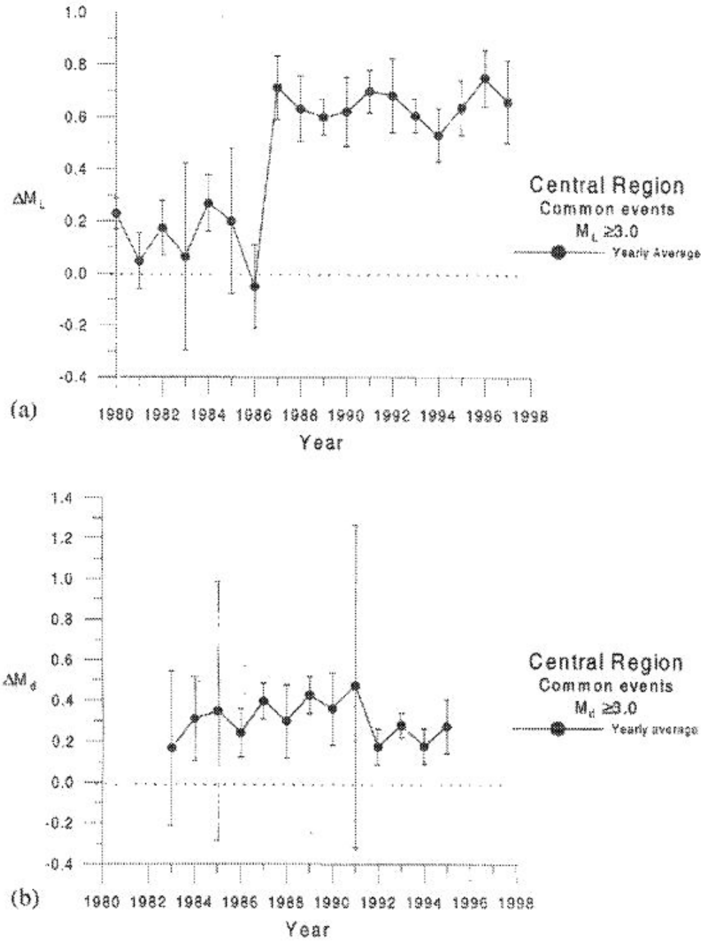


Figure 4. Yearly average of (a) ΔM_L and (b) ΔM_d obtained for the NEIC and ING catalogues, considering the common events that occurred within the Central region (Fig. 1). Error bars correspond to the 95 per cent confidence interval of the mean.

subsequent periods of time, excluding the year of transition, 1987, are as follows (the error corresponds to the 95 per cent confidence interval of the mean):

$$(1980\text{–}1986)\quad \Delta M_L = 0.13 \pm 0.05,$$
$$(1988\text{–}1997)\quad \Delta M_L = 0.64 \pm 0.04.$$

According to these average results, assuming M_L(NEIC) as a uniform reference value, an underestimation of about 0.5 can be assigned to the M_L values reported by ING since 1987.

A similar analysis, performed by replacing M_L with M_d in eq. (2), does not evidence a significant change for M_d(ING). The relevant uncertainty associated with the value of ΔM_d (Fig. 4b) for the years 1985 and 1991 is mainly due to the reduced sample size (only two events in 1985 and four in 1991). The average magnitude difference for the whole period 1983–1995 for which the sample is available is estimated to be $\Delta M_d = 0.30 \pm 0.04$.

CN: A DETECTOR OF ANOMALOUS VARIATIONS IN REPORTED MAGNITUDES

In order to understand whether the variations found in reported magnitudes can account for the anomalous behaviour of the CN functions observed in the Central region, the quantity $D = 0.5$ is added to the M_L reported by the ING bulletins, beginning in 1987. M_d values do not need to be modified because no significant time variation has been detected. CN is then applied to the Central region using the 'corrected' catalogue and following the standard procedure of forward monitoring of seismicity: learning is not repeated and the parameters are kept unchanged. The time diagram obtained is shown in Fig. 5 and clearly indicates that the anomalous behaviour of some CN functions, shown in Fig. 2, is no longer present.

Obviously, this magnitude transformation cannot be used to correct the catalogue and the magnitude revision must be

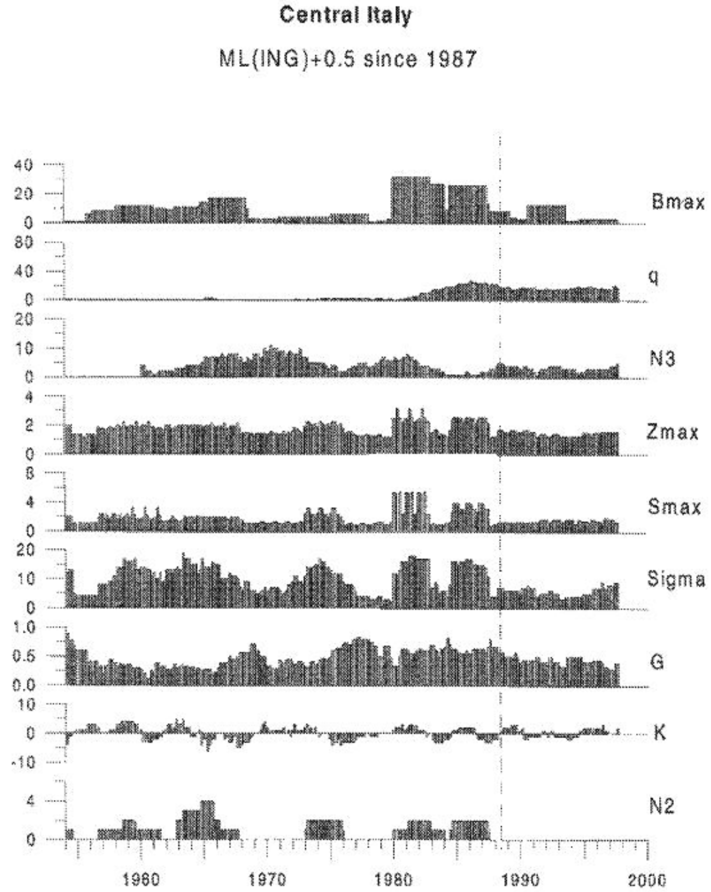


Figure 5. Time diagrams of the CN functions obtained for the Central region using the 'corrected' catalogue, in which the quantity $D=0.5$ is added to M_L(ING) beginning in 1987.

performed using all the available information (especially concerning variations in the acquisition system), not only that provided by the catalogue itself. Furthermore, a simple magnitude shift, estimated from a limited sample, cannot restore all the properties of the real seismic sequence.

Several tests performed by systematically increasing or decreasing the operating magnitude in the catalogue used for CN monitoring (Peresan & Rotwain 1998) show that the functions G, Sigma, Z_{max} and S_{max} (Table 1) are sensitive to long-lasting major magnitude underestimations of about half a magnitude unit: they became abnormally constant for relatively long periods of time, while the function q keeps very high values, but do not cause any TIP activation. On the other end, magnitude overestimations lead to unusually high values, especially for the functions N_2 and N_3, that can be used to identify and therefore discard possible TIPs declared by CN.

EXTENSION OF THE ANALYSIS TO THE WHOLE ITALIAN REGION

The magnitude differences have also been analysed within the Northern and Southern regions defined for the application of CN to the Italian territory (Peresan *et al.* 1998a). In the Northern region, the results are in very good agreement with those obtained for the Central region and, on average, an increase of $+0.5$ is observed for ΔM_L in 1987. The variation in reported M_L does not affect the CN functions in the Northern region as clearly as in the Central region because the Italian catalogue (Postpischl 1985) covers an area that, towards the north, follows the Italian border and consequently is incomplete for CN application. This incompleteness has been filled in by Costa *et al.* (1996) and Peresan *et al.* (1998a) with data provided by two other catalogues: ALPOR (Catalogo delle Alpi Orientali) (1987) and NEIC, thus reducing the influence of M_L(ING) in the computation of CN functions in the Northern region. The small number of common events, and hence the insufficient sample size, does not allow any conclusive analysis in the Southern region.

The analysis of the NEIC catalogue performed by Peresan & Rotwain (1998) for the Italian area showed that for the magnitudes M_d and M_L contributed to NEIC by other agencies, M_L is 10 times more frequent than M_d. From Fig. 6 it is seen that the total yearly number of common events varies quite significantly with time. The number of common events

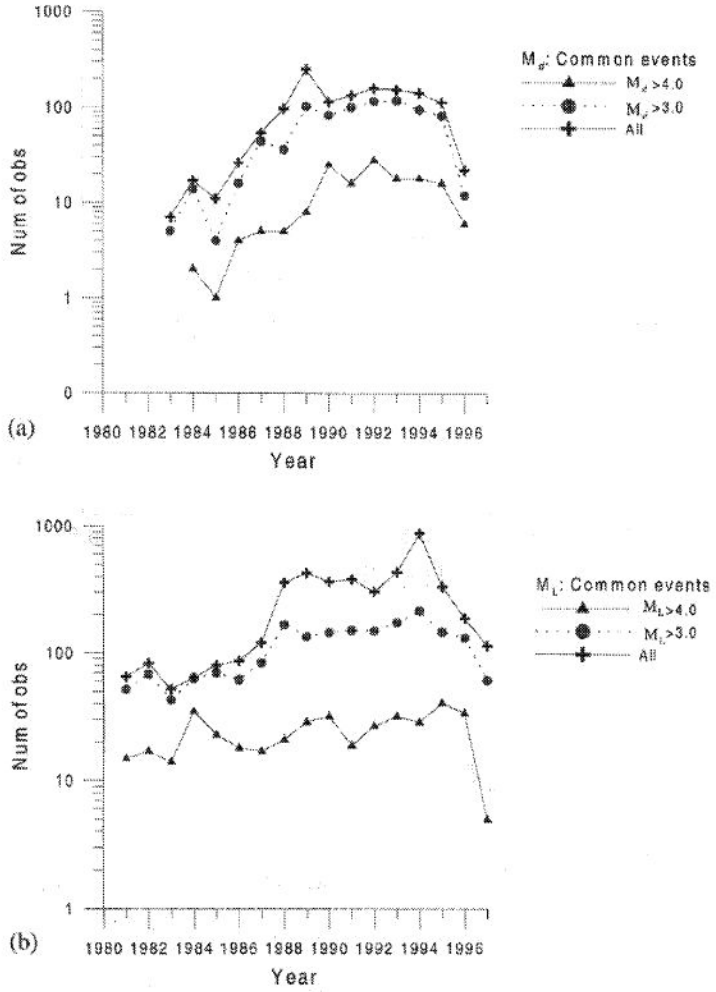


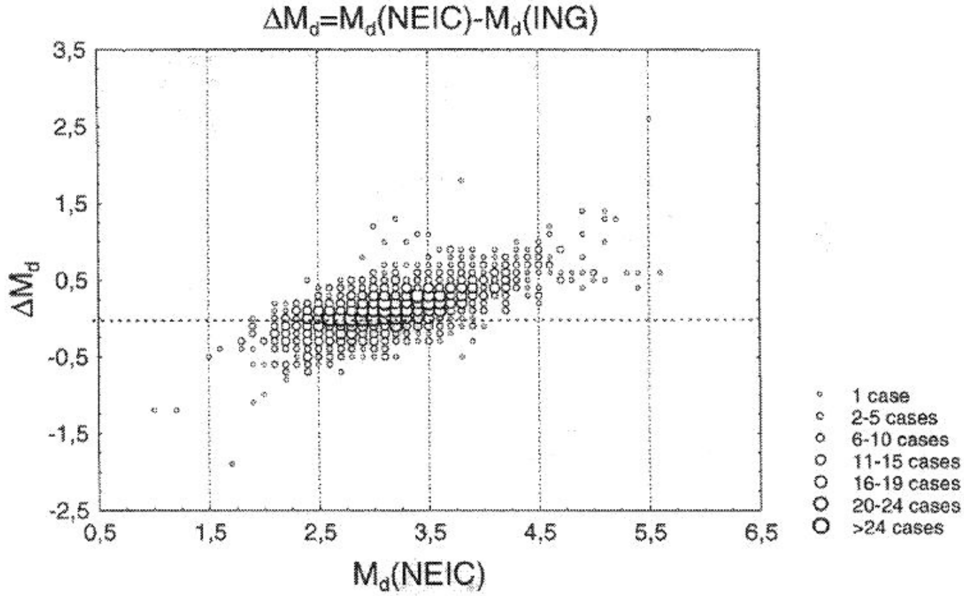
Figure 6. Yearly number of common events used for the comparison between the ING and NEIC catalogues. (a) Events used for M_d analysis; (b) events used for M_L analysis.

considerably increases after 1988, for both M_L and M_d, especially when the smaller earthquakes are considered.

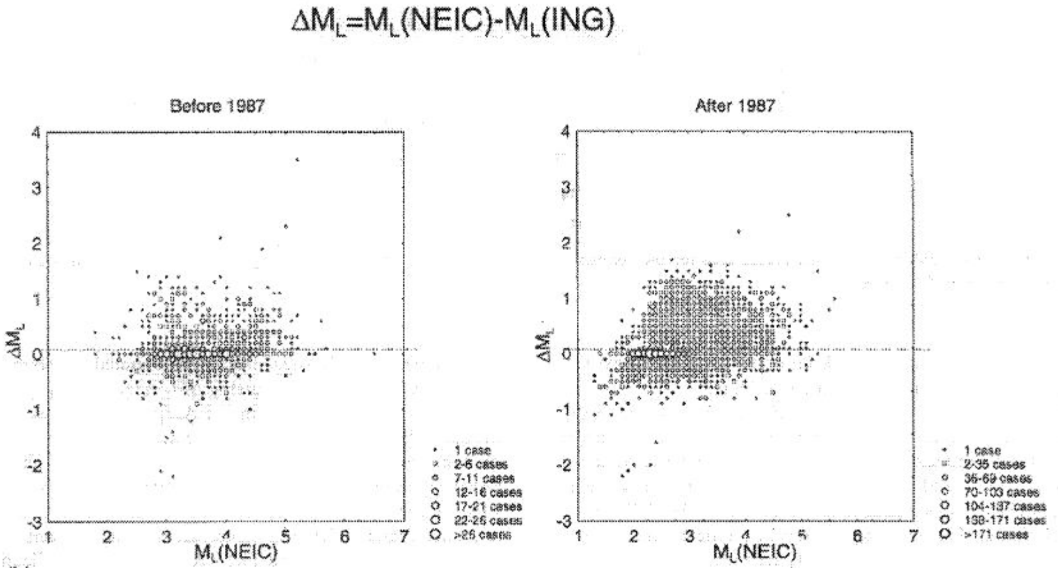
The frequency distributions of ΔM_L and ΔM_d versus NEIC magnitude are analysed to evaluate their possible correlation with the earthquakes size (Fig. 7). The linear correlation between ΔM_L and M_L(NEIC) appears quite weak, while the correlation is significant for ΔM_d versus M_d(NEIC), the correlation coefficient being about 0.7 (significant at $P < 0.05$). The distributions of ΔM_L and ΔM_d are rather different, as can easily be seen from their histograms constructed for three contiguous intervals of magnitude (Fig. 8). The values of ΔM_d appear normally distributed around mean values increasing with M_d. However, the histograms of ΔM_L are centred around $\Delta M_L = 0$, with a tail towards positive values. It seems that the set of common events can be divided into two subsets: (a) events with ΔM_L distributed around zero; and (b) events with ΔM_L distributed around 0.5.

A detailed analysis, suggested by the bimodal distribution of ΔM_L, shows that the events giving $\Delta M_L \equiv 0$ are fairly localized in space (Fig. 9). The peak in the ΔM_L histograms is due to the coincidence of M_L(ING) with the M_L contributed to NEIC by some local networks, mainly from GEN (IGG network, Dipartimento Scienze della Terra, Università di Genova, Italy), LDG (Laboratoire de Detection et de Geophysique, Bruyeres-le-Chatel, France), TTG (Seismological Institute of Montenegro, Podgorica, Yugoslavia) and TRI (OGS, Osservatorio Geofisico Sperimentale, Trieste, Italy), following the standard station codes used by NEIC. Indeed, the data reported by some local networks are used by ING to integrate the information collected by the Italian network (Fig. 8).

Fig. 6 indicates that the size of the sample becomes relatively stable for magnitudes larger than 3.0, although the yearly number of common events generally increases in 1988. Hence, in this step of the analysis also, the time behaviour of the



(a)



(b)

Figure 7. Frequency scatter plots of (a) ΔM_d and (b) ΔM_L versus the corresponding NEIC magnitude.

yearly average of ΔM_L and ΔM_d is evaluated using only earthquakes with NEIC magnitude larger than 3.0.

The yearly average values of ΔM_L and ΔM_d are shown in Fig. 10. The remarkable uncertainties on the average value of ΔM_L during the year 1983 and, similarly, of ΔM_d in 1985 are due to the large dispersion of the reported values rather than to the sample size. For the whole period 1983–1997, the yearly average of ΔM_d appears almost constant around a mean value

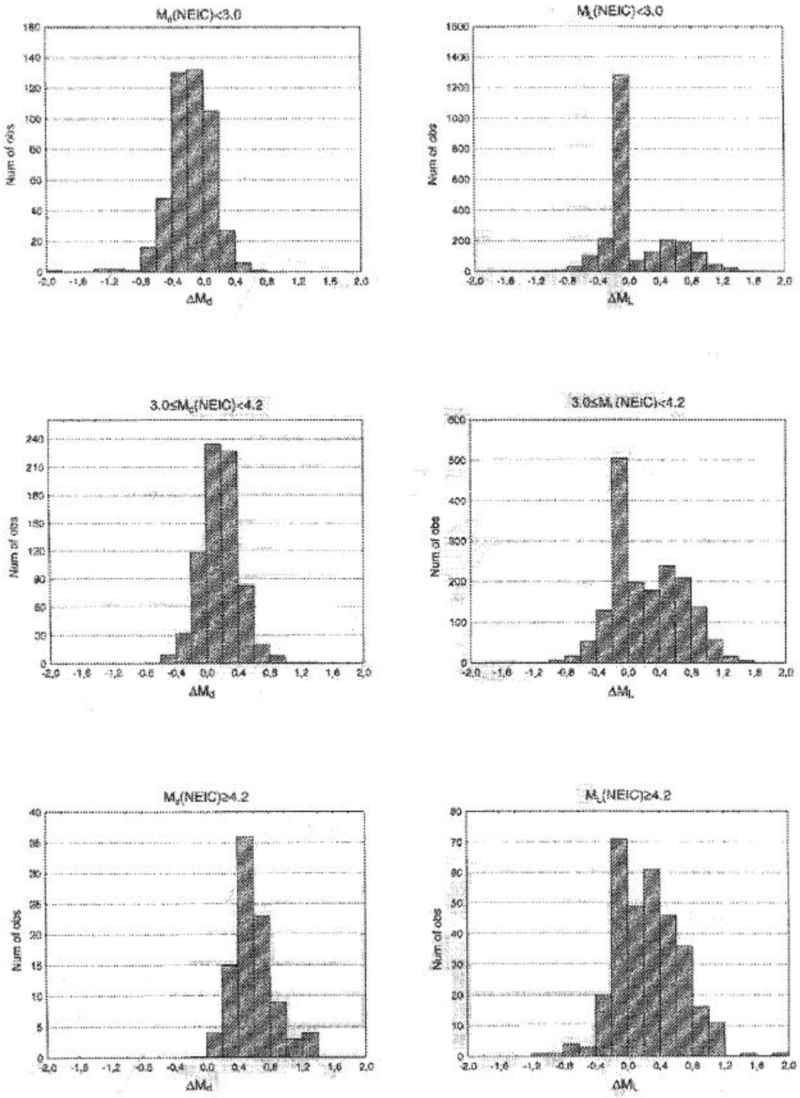


Figure 8. Histograms of the number of events versus ΔM for three contiguous ranges of magnitude for (a) ΔM_d and (b) ΔM_L. Events with ΔM lower than or equal to the upper boundary are counted in each interval.

of 0.30 ± 0.02 (Fig. 10a), in very good agreement with the results obtained for the Central region. Therefore, this analysis seems to confirm that since 1983, when they started to be reported, there have been no changes in the M_d values provided by ING. A linear relation between the M_d reported by the two agencies can be estimated by orthogonal regression of M_d(ING) versus M_d(NEIC) using the set of common events, as follows:

$$M_d(\mathrm{ING}) = 0.7 M_d(\mathrm{NEIC}) + 0.8\,. \qquad (3)$$

According to this relation, the events with $M_d(\mathrm{ING}) \geq 3.0$ are on average underestimated with respect to M_d(NEIC), while smaller events are overestimated.

The diagram of the yearly average ΔM_L (Fig. 10b), however, seems to indicate the presence of two main discontinuities: the first in 1987 and the second in 1994. The average ΔM_L, estimated for the three contiguous periods of time, are as follows (the error corresponds to the 95 per cent confidence interval of the mean):

(1980–1986) $\Delta M_L = 0.08 \pm 0.05$,
(1988–1993) $\Delta M_L = 0.30 \pm 0.04$,
(1995–1997) $\Delta M_L = 0.77 \pm 0.06$.

The ΔM_L increase observed during 1987 appears less relevant within the whole Italian area than for the Central region

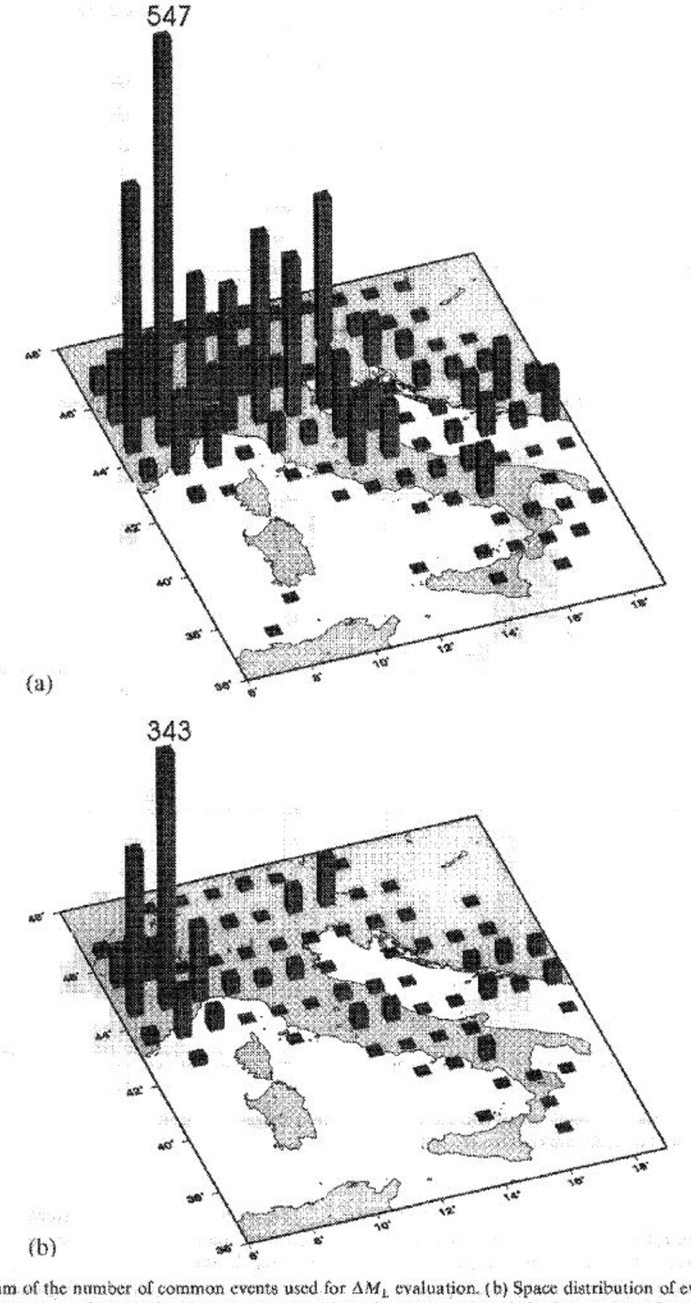


Figure 9. (a) Space histogram of the number of common events used for ΔM_L evaluation. (b) Space distribution of events with $\Delta M_L = 0$. The two histograms are plotted using the same linear scale. The maximum number of common events is indicated as a reference.

(Figs 10b and 4b). This reduction of ΔM_L can be explained by the inclusion of the M_L values contributed to both NEIC and ING by some of the neighbouring local networks, located near to the French and Slovenian borders and along the Croatian coast.

COMPARISON WITH MAGNITUDES FROM LDG BULLETINS

The use of eq. (2) for M_L reported by the catalogues ING and NEIC gives positive values for ΔM_L. To check the conclusions

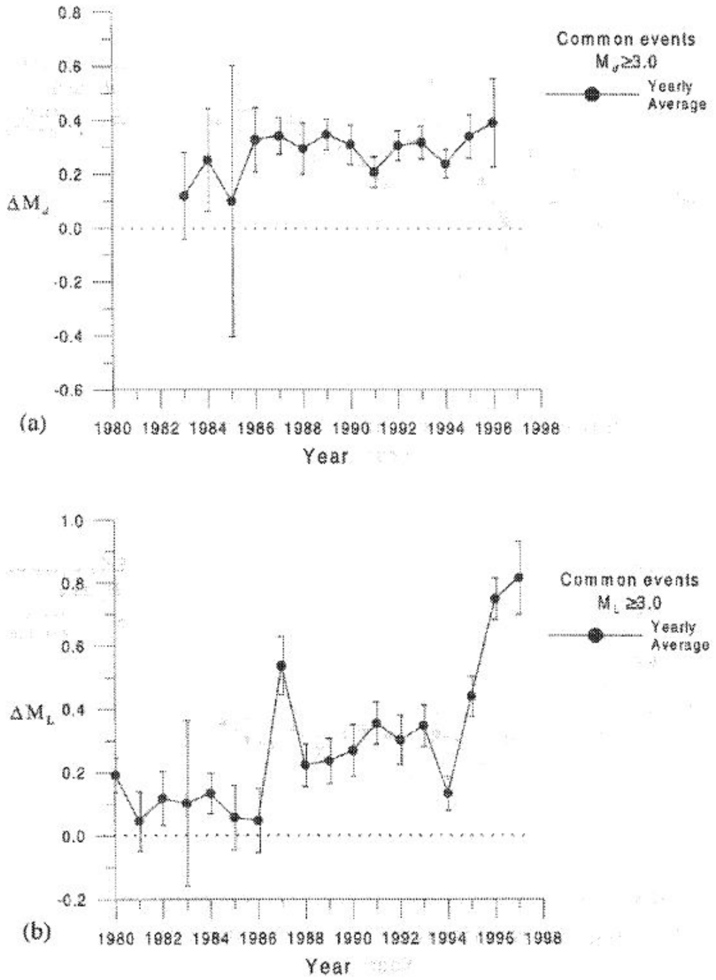


Figure 10. Yearly average of (a) ΔM_d and (b) ΔM_L for the NEIC and ING catalogues. Only events with magnitude greater than 3.0 have been considered. Error bars correspond to a 95 per cent confidence range on the calculated average. The ΔM_L minimum in 1994 is explained by the very large number of events with magnitudes coinciding with those provided by the local networks, mainly the IGG network.

drawn from the analysis of ING and NEIC data, the comparison of M_L is extended to the LDG bulletins.

The comparison between ING local magnitudes and those reported by LDG bulletins is performed within the time interval 1980–1996. About 1000 common events are selected from these regional catalogues according to the following rules: (a) time difference $\Delta t \leq 1$ min; (b) epicentral distance $\Delta\text{Lat} = \Delta\text{Lon} \leq 0.1$.

The bimodal distribution of ΔM_L observed in the comparison with the NEIC catalogue (Fig. 8) becomes even more marked when the ING and LDG magnitudes are considered. Nevertheless, most of the events with $\Delta M_L \equiv 0$ have $M_L(\text{LDG})$ lower than 3.0. Hence, considering only events with magnitude larger than 3.0 allows us to exclude a large part of such events, whose magnitudes have very probably been provided by the same agency, while permitting us to keep events for which magnitude determinations can be considered quite reliable in regional catalogues.

The yearly average values of ΔM_L for the pairs of catalogues LDG–ING and NEIC–LDG have been estimated and are plotted in Fig. 11. The number of common events used for such estimations increases in time from about 10–15 events per year up to 30–40 events per year, and this is also apparent from the corresponding reduction of uncertainties. The average values obtained from eq. (2) for the pair of catalogues LDG–ING is always significantly greater than zero, even

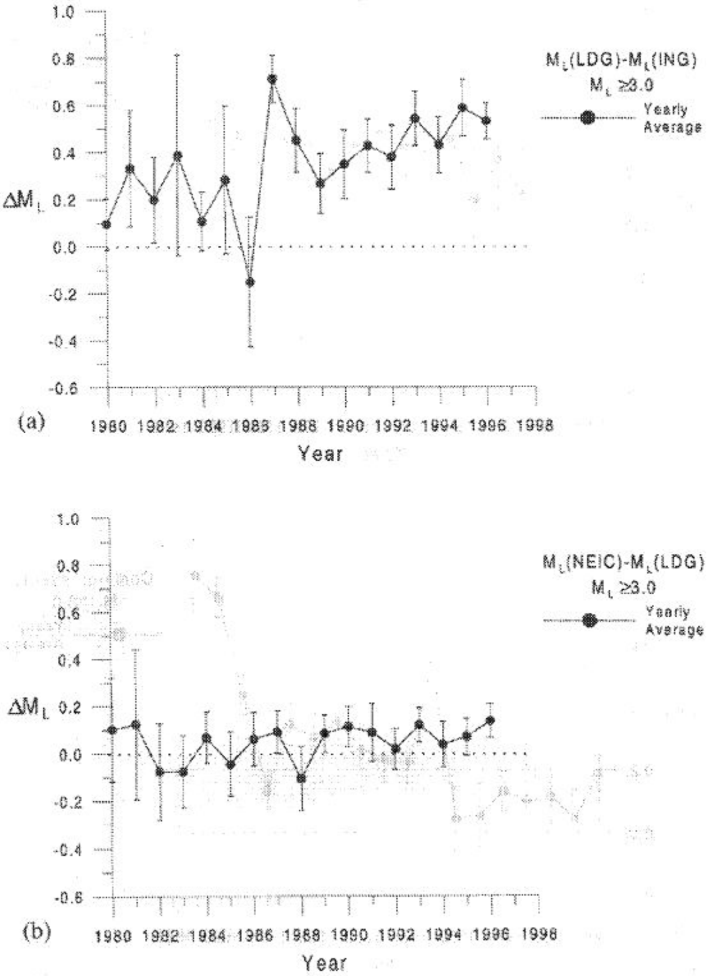


Figure 11. Yearly average of ΔM_L for (a) LDG and ING bulletins and (b) for the NEIC catalogue and LDG bulletins. Error bars indicate the 95 per cent confidence interval of the average.

with fluctuations in time (Fig. 11a). The differences ΔM_L estimated for the pair of catalogues LDG–ING and for the two intervals of time indicated in brackets give the following average values:

(1980–1986) $\Delta M_L = 0.18 \pm 0.08$,
(1988–1996) $\Delta M_L = 0.44 \pm 0.04$.

These values are in good agreement with those computed, for the whole Italian territory, comparing M_L from the NEIC and ING catalogues.

The average values ΔM_L calculated for the global catalogue NEIC and the regional bulletins LDG (about 1200 common events) are always close to zero (Fig. 11b) and, on average, are

(1980–1986) $\Delta M_L = 0.03 \pm 0.06$,
(1988–1996) $\Delta M_L = 0.08 \pm 0.03$.

This comparison seems to confirm the relative uniformity of the reference catalogues NEIC and LDG, despite the heterogeneous origin of M_L(NEIC).

A series of magnitude comparisons focused on the Central region, excluding from NEIC the events contributed by LDG or comparing directly ING and LDG, essentially confirms observations made comparing the ING and NEIC catalogues.

According to Bath (1973), we have to expect errors as large as ± 0.3 units in a calculated magnitude; nevertheless, the differences ΔM_L between the ING and the two catalogues considered have been, even after averaging, equal to or larger than $+0.3$ since 1987. Giardini *et al.* (1997) stated that local magnitudes are generally of poor quality with respect to the seismic moment, and this study indicates that they can even be inhomogeneous within the same bulletins. Unfortunately, M_L is the basic instrumental magnitude in the Italian catalogue, while M_d has only been reported since 1983.

CONCLUSIONS

Prediction methods based on seismic precursors are sometimes criticised for their sensitivity to the unavoidable catalogue errors and undeclared changes in the evaluation of the reported magnitudes (Habermann 1991; Habermann & Creamer 1994; Peresan *et al.* 1998b). This study provides a real example, showing the effect of a long-lasting systematic magnitude underestimation on CN predictions.

The absence of moderate events detected by CN functions and consequently the unusual decrease of the seismicity rate within the Central region used for the CN monitoring in Italy lead us to check for possible systematic errors in the reported magnitudes.

A detailed comparative analysis, focused on M_L and M_d, has been performed between ING and NEIC catalogues, within the area corresponding to the Central region. The magnitude differences ΔM_d appear quite stable in time and small, while a variation of about 0.5 has been found in ΔM_L, starting in 1987. This difference decreases to about 0.2 when the analysis is extended to a wider area including the whole Italian territory, but there is always an underestimation of the M_L values given by ING with respect to NEIC. The comparison extended to a third catalogue, the LDG bulletins, confirms such underestimation.

The robustness of the CN algorithm has been successfully tested with respect to the partial replacements in the catalogue, provided the homogeneity of data is preserved (Peresan & Rotwain 1998), and with respect to the short-term inadvertent increase in reported magnitude indicated by Zuniga & Wyss (1995) for the Italian catalogue, which does not seem to affect the results of predictions (Peresan *et al.* 1998a).

Therefore, our study indicates that a careful analysis of CN functions allows us to find major long-lasting undeclared changes in the reported magnitudes and may permit us to separate such effects from the anomalies in the seismic flow that define the times of increased probability (TIPs) for the occurrence of a strong event. The results of our analysis cannot be used for catalogue correction; therefore, the ING catalogue cannot be used for CN monitoring and one has to make use of a different data set such as the NEIC catalogue.

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REFERENCES

ALPOR, 1987. *Catalogue of the Eastern Alps.* Osservatorio Geofisico Sperimentale, Trieste, Italy (computer file).

Bath, M., 1973. *Introduction to Seismology,* Birkhauser, Basel.

Costa, G., Panza, G.F. & Rotwain, I.M., 1995. Stability of premonitory seismicity pattern and intermediate-term earthquake prediction in central Italy, *Pure appl. Geophys.,* **145,** 259–275.

Costa, G., Stanishkova, I.O., Panza, G.F. & Rotwain, I.M., 1996. Seismotectonic models and CN algorithm: the case of Italy, *Pure appl. Geophys.,* **147,** 1–12.

Gabrielov, A.M. *et al.,* 1986. *Algorithms of Long-Term Earthquakes' Prediction,* International School for Research Oriented to Earthquake Prediction-algorithms, Software and Data Handling, Lima, Perù.

Giardini, D., Di Donato, M. & Boschi, E., 1997. Calibration of magnitude scales for earthquake of the Mediterranean, *J. Seism.,* **1,** 161–180.

Habermann, R.E., 1991. Seismicity rate variations and systematic changes in magnitudes in teleseismic catalogs, *Tectonophysics,* **193,** 277–289.

Habermann, R.E. & Creamer, F., 1994. Catalog errors and the M8 earthquake prediction algorithm, *Bull. seism. Soc. Am.,* **84,** 1551–1559.

Keilis-Borok, V.I., 1996. Intermediate term earthquake prediction, *Proc. Nat. Acad. Sci. USA,* **93,** 3748–3755.

Keilis-Borok, V.I. & Rotwain, I.M., 1990. Diagnosis of time of increased probability of strong earthquakes in different regions of the world: algorithm CN, *Phys. Earth planet. Inter.,* **61,** 57–72.

Keilis-Borok, V.I., Kutznetsov, I.V., Panza, G.F., Rotwain, I.M. & Costa, G., 1990. On intermediate-term earthquake prediction in Central Italy, *Pure appl. Geophys.,* **134,** 79–92.

Peresan, A., Costa, G. & Vaccari, F., 1997. CCI1996: the current catalogue of Italy, *Internal Rept IC/IR/97/9.* International Centre for Theoretical Physics, Trieste, Italy.

Peresan, A., Costa, G. & Panza, G.F., 1998a. Seismotectonic model and CN earthquake prediction in Italy, *Pure appl. Geophys.,* **154,** 281–306.

Peresan, A. & Rotwain, I.M. & Panza, G.F., 1998b. Evaluation of the stability of algorithm CN with respect to random errors in magnitude: Central Italy, *Ann. Geophys., Abstract Suppl.,* **16,** 1091.

Peresan, A. & Rotwain, I.M., 1998. Analysis and definition of magnitude selection criteria for NEIC (PDE) data, oriented to the compilation of a homogeneous updated catalogue for CN monitoring in Italy, *Internal Rept,* International Centre for Theoretical Physics, Trieste, Italy.

Postpischl, D., 1985. *Catalogo dei Terremoti Italiani dall'anno 1000 al 1980,* CNR–Progetto Finalizzato Geodinamica, Bologna, Italy.

Rotwain, I. & Novikova, O., 1999. Performance of the earthquake prediction algorithm CN in 22 regions of the world, *Phys. Earth planet. Inter.,* **111,** 207–213.

Storchak, D.A. & Bird, A.L. & Adams, R.D., 1998. *Location Discrepancies,* XXVI General Assembly of ESC, Tel Aviv, Israel.

Zuniga, F.R. & Wyss, M., 1995. Inadvertent changes in magnitude reported in earthquake catalogs: their evaluation through the b-value estimates, *Bull. seism. Soc. Am.,* **5,** 1858–1866.