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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.

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Abstract

In the present work we describe the construction of an updated catalogue for the Italian territory, necessary for intermediate-term earthquake prediction using algorithm CN. Due to the inaccessibility of data from the local network, we established to update the Italian catalogue CCI1996 using the Preliminary Determinations of Epicentres (PDE) from NEIC. Since CN requires an input catalogue that must be, as much as possible, homogeneous in space and time, it has been necessary to perform a preliminary analysis. Therefore, the completeness of PDE catalogue is studied and the relations between different kind of magnitudes reported in the CCI1996 and PDE catalogues are analysed, in order to formulate a rule for the choice of magnitude priority in PDE, similar to that used for CCI1996. The results of CN monitoring of Italian seismicity, updated to July 1998, are given here.

Introduction

The algorithm CN (Gabrielov et al., 1986; Keilis-Borok and Rotwain, 1990) allows us to indicate, on the basis of the analysis of seismicity, the Times of Increased Probability (TIP) for the occurrence of an event with magnitude greater than a fixed threshold M_0. Thanks to the normalisation of its functions, CN can be applied to regions with a different seismicity level without any adjustment of parameters, when the general conditions of applicability of the algorithm are satisfied. CN application to a fixed region consists of two steps: at a first stage, referred to as learning step, the magnitude M_0, the magnitudes for normalisation of functions and the thresholds for discretization of functions are defined. In the second step the monitoring of seismicity is performed using the parameters fixed in the learning phase. The catalogue homogeneity among the different steps of the analysis is a relevant question, because it can significantly influence the results.

The regionalization used for the application of the algorithm in Italy has been defined by Peresan et al. (1997a), on the basis of the seismotectonic model of the Italian territory proposed by Scandone et al. (1990; 1994) and it is composed of three regions, corresponding approximately to the North, Centre and South of Italy (Fig. 1).

The catalogue used for CN application in Italy up to July 1997 was the CCI1996 (Peresan et al., 1997b); this catalogue is composed of the revised PFG catalogue (Postpischl, 1985), for the period 1000-1979, and since 1980 was updated by us with the ING bulletins. Due to the inaccessibility of the ING (Istituto Nazionale di Geofisica) data set since July 1997, we established to update the catalogue using different data. Among the currently available databases, the only one suitable for CN application seems to be the catalogue of Preliminary Determinations of Epicentres (PDE) from NEIC. This catalogue is rapidly enough updated and it is quite complete for our purposes, even if its completeness appears lower than that of the CCI1996, especially going back in the past.

Nevertheless, the upgrading performed using data from a different source could make the catalogue inhomogeneous, influencing the values of functions. Therefore, in order to construct a homogeneous updated catalogue for CN application, it is necessary to perform the following preliminary analysis:

- Study of the completeness of the PDE catalogue;

- Study of the relations between different kinds of magnitudes reported in the CCI1996 and PDE catalogues;
- Formulation of a rule for the choice of magnitude priority in PDE, similar to the priority used for CCI1996.

In the present study all these aspects will be analysed and the results of monitoring of seismicity, updated to May 1998, will be given.

Scheme of the analysis

The monitoring of seismicity with algorithm CN, for intermediate-term earthquake prediction purposes, is performed with a time step of two months and requires a catalogue updated with a time delay of a couple of weeks. Since the Italian catalogue of earthquakes, currently compiled by ING, ceased to be distributed after June 1997, the necessity arose to make use of a different data set for the upgrading. Among the available data-base we established to use the PDE data (Preliminary Determinations of Epicentres yearly, monthly and weekly revised versions) and the QED (Quick Epicentral Determinations), officially distributed by NEIC via ftp (Earthquake Hypocentres Data File version).

The PDE catalogue, analysed for the entire Italian area (rectangle with Lat: 35-50N and Lon: 5-20E), appears to satisfy the general conditions required for CN application in Italy, since it can be considered complete for magnitudes greater than 3.0, at least after 1985, and it is updated rapidly enough. Besides, CN requires an input catalogue that must be, as much as possible, homogeneous also in space and time and this has to be checked for each one of the three subcatalogues for the areas corresponding to Northern, Central and Southern regions.

The time homogeneity of the catalogue can be evaluated on the basis of the Gutenberg-Richter distribution. In the present case we are mainly concerned about the possible inhomogeneity that may result appending the PDE catalogue to the CCI1996 catalogue (briefly indicated as CCI in the following). Therefore we wish that the slope of the frequency-magnitude distribution does not change significantly passing from one catalogue to the other. Moreover we'll expect that, for a fixed common interval of time, the two distributions will be comparable in terms of G-R parameters and number of events. Both these comparisons however depend on the choice of magnitude that is made for PDE catalogue, that must be performed with a criterion homogeneous to the priority order selected for the CCI catalogue. Indeed, CCI contains four estimations of magnitude: duration magnitude M_d, magnitude from intensities M_I, local magnitude M_L and body wave magnitude m_b from ISC; the priority used to select the operating magnitude in CCI is: M_L, M_d, M_I; m_b from ISC is not used, since it is given just for a few events and for a limited period of time. In the PDE catalogue, for each record, there are four possible different estimations of magnitude: m_b from NEIC, M_S from NEIC, M1 and M2; the last two values may correspond to magnitudes of a different kind provided from different agencies. A preliminary analysis of the catalogue allowed us to evidence that, for the Italian area, both M1 and M2 contain mainly M_d and M_L (M_L are more frequent than M_d, with a rate of 10/1). Since it is necessary to define a priority for PDE catalogue that allows a choice of magnitude similar to that of the CCI catalogue, we established to perform the following analysis, for each one of the three regions:

1. a subcatalogue of events common to the CCI and PDE is selected and all magnitudes from one catalogue are compared to the four estimations of the other catalogue. The linear regression (minimising distances normal to the fitting line), the standard deviation σ and the percentage P of points falling outside 2σ are calculated for each pair of magnitudes;
2. for each of the three magnitudes M_L, M_d and M_I from the CCI catalogue a corresponding magnitude from PDE is selected, according to the rule that the standard deviation σ is minimal for this magnitude, P is small, and the parameters A and B of the straight-line: M(CCI)=BM(PDE)+A are as close as possible to zero and one, respectively. Once the correspondence between magnitudes is found, the priority defined for the CCI catalogue can be transferred to the PDE;
3. the operating magnitude is selected from PDE according to the priority fixed as in step 2, both using original values of M and for M'=BM+A, recalculated using the parameters A and B of the corresponding M(CCI)-M(PDE) regression;
4. the operating magnitude from CCI and PDE are compared, considering the $M_{priority}$(CCI)-$M_{priority}$(PDE) distribution and the G-R relation. Among the possible choices (for equivalently good priorities and with or without recalculation of magnitudes), the one giving a good linear extrapolation

and, above all, producing a frequency-magnitude relation closer to that from CCI, is retained.

Once selected the operating magnitude, the catalogue for monitoring is compiled using the CCI data for the learning period and the PDE data during the period of forward analysis. In this way the learning is performed using the best available data, since the Italian catalogue is more complete than the PDE, especially in the past, while real monitoring is done using the currently updated available data.

Priority choice for the three different regions

Northern region

The comparison of magnitudes for the Northern region is performed extracting a subcatalogue of common events for the PDE and the catalogue used for CN monitoring in Northern Italy. Indeed, here the data from the CCI catalogue were integrated with the information contained in the ALPOR(1987) and NEIC catalogues, because the Italian catalogue was fairly uncomplete outside the political boundaries. Here we will refer to the catalogue CCI+ALPOR+NEIC as Northern catalogue. The area considered for this analysis is the rectangle of coordinates: Lat:41.0-46.6N, Lon:8.0-16.0E, including the whole polygon that delimits the Northern region, while the time interval goes from the beginning of 1950 to the end of 1985. The selection of common events is performed considering equivalent the records differing in time less than 1 minute and 1 degree in epicentral coordinates, while depth and magnitudes are not considered.

In the Northern catalogue the operating magnitude is chosen as the maximum among $M_{ALPOR}(M_L, M_I)$, $M_{CCI}(M_L, M_d, M_I)$ and $M_{NEIC}(M1, M_S, m_b)$, selected from initial catalogues according to the priority order reported in brackets. Each one of the 1620 equivalent events extracted can be consequently associated to 3 estimations of magnitude from the Northern catalogue and 4 estimations of magnitude, m_b, M_S, M1 and M2 in the PDE catalogue. Therefore it appears necessary to find out for each magnitude given in the Northern catalogue a different representative priority from the PDE catalogue and after to select the maximum among these corresponding values.

The relations between different kinds of magnitudes have been evaluated calculating the parameters for the linear fitting, the standard deviation σ and the percentage P of events outside 2σ. Considering the diagrams of M_{ALPOR} versus different magnitudes from PDE, we observe that M_{ALPOR} is well fitted by M1(PDE) and M2(PDE), while just a few points are available for M_S(PDE) and dispersion becomes very large for m_b(PDE). Consequently, to select from PDE a magnitude corresponding to M_{ALPOR} a proper priority order can be: M1, M2, M_S.

To select a magnitude corresponding to M_{CCI}, all the possible regression between the different magnitudes given in the CCI and in the PDE catalogue have been considered for the equivalent events which occurred within the fixed space-time interval. In this case a good linear extrapolation has been obtained between M_L(CCI) and M1(PDE) and between M_d(CCI) and M2(PDE), for M_S(PDE) the small number of points does not allow to establish any clear relation, while m_b(PDE) does not seem representative of any of the CCI magnitudes. Therefore M_{CCI} should be also properly represented by PDE magnitudes selected according to the priority: M1, M2, M_S.

Finally, for M_{NEIC} magnitude, we established to keep for the PDE data, that are provided from the same NEIC agency, the same priority order M1, M_S, m_b used to construct the Northern catalogue.

Once the three priority magnitudes corresponding to M_{ALPOR}, M_{CCI} and M_{NEIC} are selected from PDE, the operating magnitude can be taken as the maximum among them, just as it is routinely done for the Northern catalogue. The diagram of the operating magnitudes $M_{Max}(PDE_{priority})$ versus $M_{Max}(M_{Alpor}, M_{CCI}, M_{NEIC})$ for the common events, allows a good linear extrapolation y=A+Bx, with B=0.92 and A=0.30. The standard deviation for the fitted line is 0.22 and 5% of the points lie outside 2σ.

Nevertheless we observed that this complex priority choice is practically equivalent to pick directly the maximum magnitude from PDE, since the distribution M_{Max}(PDE) versus $M_{Max}(M_{Alpor}, M_{CCI}, M_{NEIC})$ is identical to that obtained using $M_{Max}(PDE_{priority})$ and gives the same values for A, B, for the linear extrapolation reported in Fig. 2. This observation is confirmed by the Gutenberg-Richter relations obtained with these two different choices of M (Fig. 3), that are almost identical; therefore it has little meaning to use the complex procedure and in the forward monitoring the operating magnitude will be selected simply as M_{Max}(PDE).

From Fig. 3 we can observe that the PDE catalogue, using M=M_{Max}(PDE) and for the time interval 1986-1997, can be considered complete for $M \geq 3.0$; besides it has a slope very close to that of the Northern catalogue in the previous period of time (1950-1985), at least in the range of intermediate size earthquakes (3.0-4.5). Therefore PDE determination, with this magnitude priority choice, appears adequate for the catalogue upgrading in the Northern region.

Central Region

The analysis of magnitudes for Central Italy is performed within the rectangle of coordinates: Lat:39.0-45.5N, Lon:8.0-17.5E. The time interval considered goes from the beginning of 1900 to the end of 1997.

As a first step we extracted a subcatalogue of events common to both CCI and PDE catalogue, which occurred from 1900 up to the whole 1985; the selection of common events is made allowing a difference in origin time equal to 1 minute and 1 degree for epicentral coordinates, while depth and magnitudes are not considered. For the 1520 common events extracted from the two catalogues, the relations between different kinds of magnitudes in the CCI and PDE catalogue are considered (Figures 4a,b,c,d). For each diagram the values of the parameters for the linear fitting, the standard deviation and the percentage P of points outside 2 standard deviations from the line, are reported. For each kind of magnitude used in the CCI catalogue a corresponding magnitude from PDE is selected, according to the rule that the standard deviation is minimum and the parameters A and B of the linear extrapolation are closer to zero and one, respectively (see Figures 4a,b,c,d). Consequently M_L(CCI) can be associated to M2(PDE) and M_d(CCI) to M1(PDE); for M_S(PDE) the statistic is very poor, hence it will be kept only as a last chance, while m_b(PDE) does not seem representative of any one of the magnitudes considered in CCI catalogue. According to this analysis, the choice of priority: M2, M1, M_S from PDE, should be similar to the priority used in the learning period in this region.

The magnitudes from PDE, however, can be used in two different ways: they can be recalculated into the corresponding CCI magnitude, using the coefficients obtained from the linear regression, or they can be used without any recalculation. The cumulative frequency-magnitude graph (Fig. 5), normalised by time, shows that the differences between the three curves obtained for CCI (time: 1900-1985) and PDE (time: 1986-1997), both recalculated or not, are almost negligible for magnitude greater than the completeness level. Besides, for earthquakes with magnitude between 4.5 and 5.5 (that is the range of magnitude considered for the evaluation of functions), the PDE operating magnitude obtained without recalculation gives a curve closer to CCI. Therefore we established to select the magnitude from PDE according to the priority order: M2, M1, M_S, without any recalculation.

Southern Region

An analysis similar to that described for the Central region, has been performed for Southern Italy, checking the catalogue within the rectangular area of coordinates: Lat: 37.0-42.0N, Lon: 12.0E-17.5E. Magnitudes for the common events extracted from the CCI1996 and PDE catalogues have been compared for the time interval 1900-1985, considering the relations between all the different M(CCI)-M(PDE) pair of magnitudes. From Fig. 6a,b,c,d it is possible to observe that the best linear extrapolation for M_L(CCI) is obtained for M1(PDE), but also M2(PDE) and m_b(PDE) provide a good estimation for M_L(CCI), while no clear correspondence can be established for M_d(CCI) and M_I(CCI) magnitudes. Besides, just as in the Northern and Central regions, we observed that recalculation of magnitudes does not improve significantly the homogeneity among the CCI and PDE catalogues (Figures 7 and 8). Therefore we established to choose the operating magnitude for the Southern region according to the priority order: M1, M2, m_b without recalculation.

Comparing the frequency-magnitude relations, normalised by time, obtained for the two catalogues CCI1996 (1900-1985) and PDE (1986-1997) the seismic activity appears to be significantly lower in the PDE determinations, even if the total number of events it is even larger (Fig. 7). Nevertheless, this difference almost disappears when considering the catalogue of main shocks only (Fig. 8) and this can be explained by the fact that in this area many events are reported in the PDE catalogue without any estimation of magnitude. A further analysis of PDE completeness for Southern Italy shows us that this catalogue cannot be considered complete for magnitudes lower than M=4.0 before 1992, and for M=3.5 up to the present time. The lower completeness level must be taken into account both during the construction of the catalogue for the monitoring of seismicity and in the evaluation of results, since it increases the risk of failures to predict.

Results of CN monitoring in Italy

The analysis and comparison of PDE and CCI catalogues described in this work allows us to construct an updated catalogue as homogeneous as possible, indicating for each region the proper selection of the operating magnitude from the PDE catalogue. Wishing to perform the learning step with a better quality and homogeneous set of data, we established to compile the catalogue for CN monitoring using CCI1996 data for the learning period and the PDE data during the period of forward analysis, since the Italian catalogue is more complete than PDE, especially in the past.

Northern region

The updated catalogue for the Northern Region (Fig. 1a) is composed by the Northern catalogue (ALPOR+CCI+NEIC) for the time interval 1964-1994, corresponding to the learning period, and by the PDE determinations since 1995, that is the period of forward predictions. According to the results of our analysis, the operating magnitude for PDE in this area is chosen to be the maximum M_{Max}(PDE), while for the Northern catalogue it is the maximum among $M_{ALPOR}(M_L, M_I)$, $M_{CCI}(M_L, M_d, M_I)$ and $M_{NEIC}(M_L, M_S, m_b)$.

The results of application of CN algorithm, updated at May, 1st 1998, can be summarized as follows: all the four strong earthquakes with $M \geq M_0 = 5.4$ which occurred within the region, from March 1964 to May 1998, are correctly preceded by a TIP, with alarms covering about 25% of the total time and two false alarms. The diagram showing the time distribution of TIPs and the occurrence of strong events in the Northern region is given in Fig. 9a. No alarm is currently indicated for this region.

Central region

The catalogue for CN application in Central Italy (Fig. 1b) is constructed using the CCI from 1954 to 1985, that corresponds to the learning period, and the PDE catalogue since 1986. The priority used for the CCI catalogue is

$M_{CCI}(M_L, M_d, M_I)$, while for the PDE in the Central region the operating magnitude is $M_{PDE}(M2, M1, M_S)$.

The results of application of CN algorithm in Central Italy are represented in Fig. 9b and can be described as follows: all the five strong earthquakes with $M \geq M_0 = 5.6$, which occurred within the region from 1954 to May 1998, are correctly identified with TIPs covering about 22% of the total time and there are two false alarms. The forward monitoring, updated to May 1998, indicates a current alarm for this region from 26.9.1997 to 1.5.1999.

Southern region

The completeness threshold for the PDE catalogue in Southern Italy is about M=4.0 up to 1992, and reaches M=3.5 only since 1992 (Fig. 8). Therefore, due to the lower completeness level of data in this area, it is not possible to compile the catalogue using the PDE for the whole period of forward analysis, but it is necessary to keep CCI at least up to 1991. Indeed, the functions of seismic flow in Southern region are evaluated using the events with $M \geq 3.8$, while for the counting of aftershocks the earthquakes with $M \geq 3.0$ are considered. Hence using PDE data since 1992, we must bear in mind that one precursor, based on bursts of aftershocks, could be lost due to the lack of aftershocks, and this increases the probability of failures to predict. Keeping into account these necessary warnings, the updated catalogue for Southern Italy can be compiled using the CCI for the period: 1954-1991, with magnitude priority $M_{CCI}(M_L, M_d, M_I)$, followed by the PDE (1992-1998), with priority $M_{PDE}(M1, M2, m_b)$.

The results of the monitoring updated to May, 1 1998 are the following: all the four strong events with $M \geq M_0 = 5.6$ are correctly identified by retrospective analysis, with TIPs covering about 31% of total time and with 5 false alarms. The time distribution of alarm periods and the time of occurrence of strong events are represented in Fig. 9c. No current alarm is indicated for Southern Italy.

Conclusions

The results obtained indicate that the PDE catalogue is appropriate for forward prediction of strong earthquakes in Italy, once the proper operating magnitude is chosen. Indeed, using the updated CCI+PDE catalogue compiled according to the rules defined here, all the four strong earthquakes, which occurred during the period of forward monitoring both in the Northern and Central regions, are correctly predicted. This means that CN algorithm can detect the symptoms of instability in the PDE catalogue, with the same parameters and discretization thresholds fixed during the learning period with the CCI catalogue. Special attention must be payed however to the Southern region, where the lower completeness level of data increase the probability of failures to predict.

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Figure captions

Fig. 1 - Regionalization of the Italian territory proposed by Peresan et al. (1997a) and following closely the seismotectonic model. a) Northern Region; b) Central Region; c) Southern Region.

Fig. 2 – Relation between the operating magnitude in the Northern catalogue (Alpor+CCI+NEIC), selected as $M_{Max}(M_{Alpor}, M_{CCI}, M_{NEIC})$, and the maximum magnitude from PDE, without recalculation. Only the events common to both catalogues, which occurred within the fixed rectangle in the period of time 1950-1985, are considered here.

Fig. 3 – Cumulative frequency-magnitude relations, normalised by time, obtained for the Northern catalogue (Alpor+CCI+NEIC) and for the PDE catalogue, considering both $M_{Max}(PDE_{priority})$ and $M_{Max}(PDE)$ simply. All the events which occurred within the rectangle with coordinates: Lat:37.0-42.0N Lon:12.0-18.0E are considered. Mc is the completeness threshold required.

Fig. 4a,b,c,d – Relations between different kinds of magnitudes in the CCI1996 catalogue and the PDE catalogue for the common events occurred in the Central part of Italy (Lat: 39.0-45.5N, Lon: 8.0-17.5E). The parameters a and b of the linear fitting Y=bX+a are given for each diagram, together with the number of events N used to evaluate the linear extrapolation (with both nonzero magnitudes); sd is the standard deviation and P is the percentage of points outside two standard deviations.

Fig. 5 - Cumulative frequency-magnitude relations, normalised by time, obtained for the CCI1996 and PDE catalogues in the Central part of Italy. For the PDE catalogue two different operating magnitudes are considered: $M_{PDE}(M2, M1, M_S)$ recalculated, according to the linear extrapolations of Fig. 4, and $M_{PDE}(M2, M1, M_S)$ not recalculated.

Fig. 6a,b,c,d – Relations between different kinds of magnitudes in the CCI1996 catalogue an PDE catalogue for the common events which occurred in the Southern part of Italy (Lat: 37.0-42.0N, Lon: 12.0-17.5E). The parameters a and b of the linear fitting, the number of events N, the standard deviation sd and the percentage P of points outside two standard deviations, are given for each diagram.

Fig. 7a,b - Cumulative frequency-magnitude relations, normalised by time, obtained for a) all the events and b) main shocks only contained in the CCI1996 and PDE catalogues for Southern Italy. For the PDE catalogue two different operating magnitudes are considered: $M_{PDE}(M1, M2, m_b)$ recalculated, according to the linear extrapolations of Fig. 6, and $M_{PDE}(M1, M2, m_b)$ not recalculated. Mc is the completeness threshold required.

Fig. 8a,b – Frequency-magnitude distributions, obtained for the PDE catalogue in the Southern part of Italy, considering six different time intervals of two years duration, a) from 1986 to 1991 and b) from 1992 to 1997, respectively. The operating magnitude is $M_{PDE}(M1, M2, m_b)$ not recalculated.

Fig. 9 – Results of application of CN algorithm in Italy, updated at May, 1st 1998, using the catalogue CCI+PDE composed by the CCI1996, for the learning period, and by the PDE for the forward monitoring. Black boxes indicate the periods of alarm, while triangles indicate the occurrence of the strong earthquakes with $M \geq M_0$. The learning period and the threshold M_0 are reported for each region.

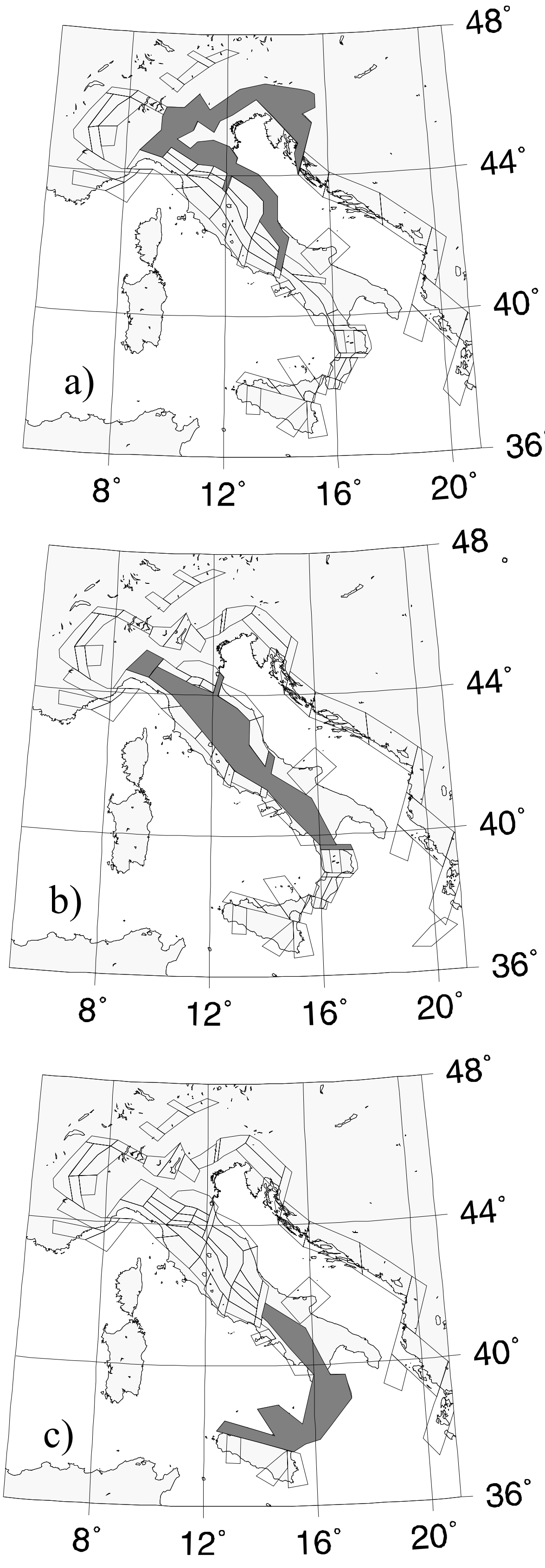


Fig. 1

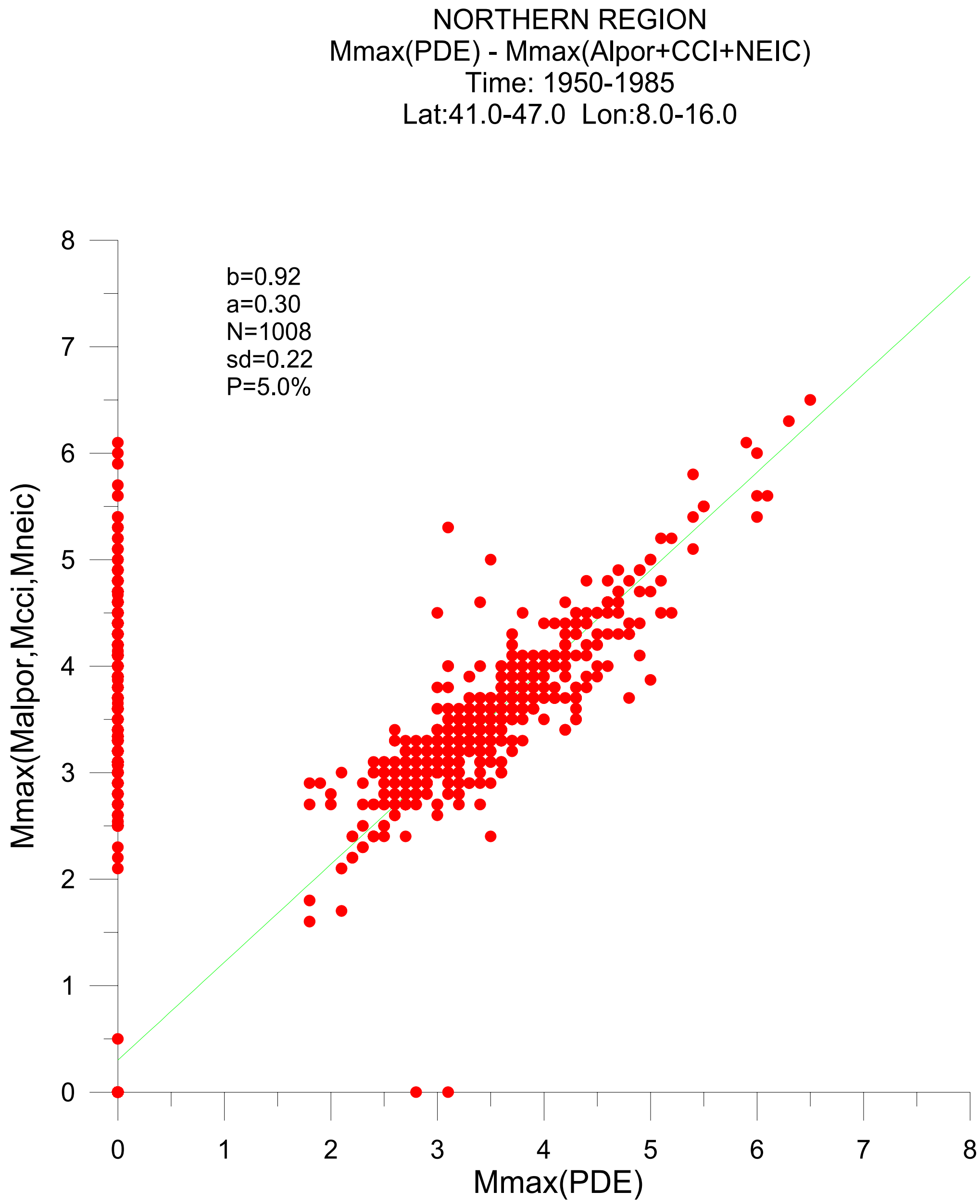

NORTHERN REGION
Mmax(PDE) - Mmax(Alpor+CCI+NEIC)
Time: 1950-1985
Lat:41.0-47.0 Lon:8.0-16.0
b=0.92
a=0.30
N=1008
sd=0.22
P=5.0%
Mmax(Malpor,Mcci,Mneic)
Mmax(PDE)
0
1
2
3
4
5
6
7
8

Fig. 2

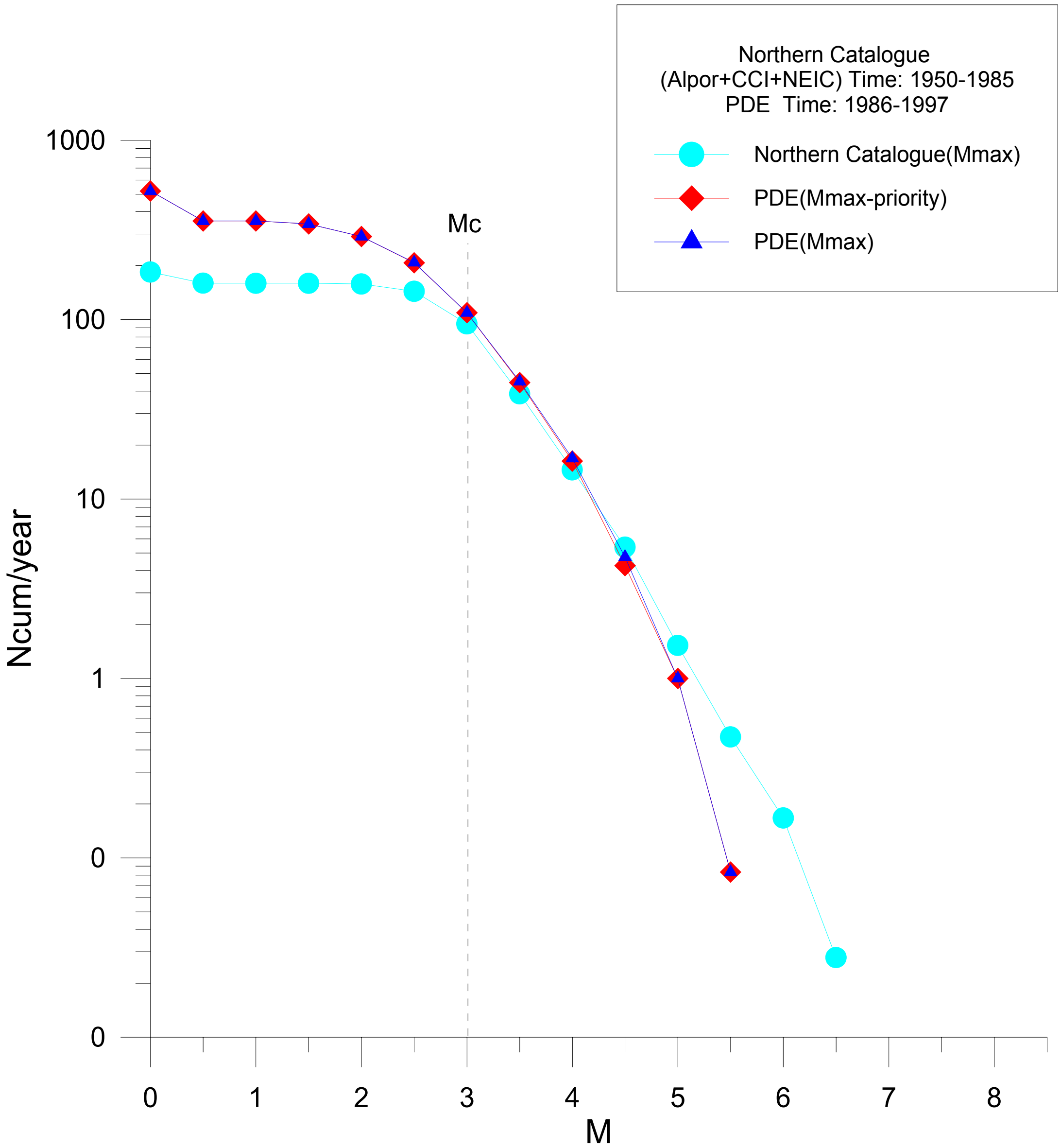

Northern Catalogue
(Alpor+CCI+NEIC) Time: 1950-1985
PDE Time: 1986-1997
Northern Catalogue(Mmax)
PDE(Mmax-priority)
PDE(Mmax)
Mc
1000
100
10
1
0
0
Ncum/year
0
1
2
3
4
5
6
7
8
M

Fig. 3

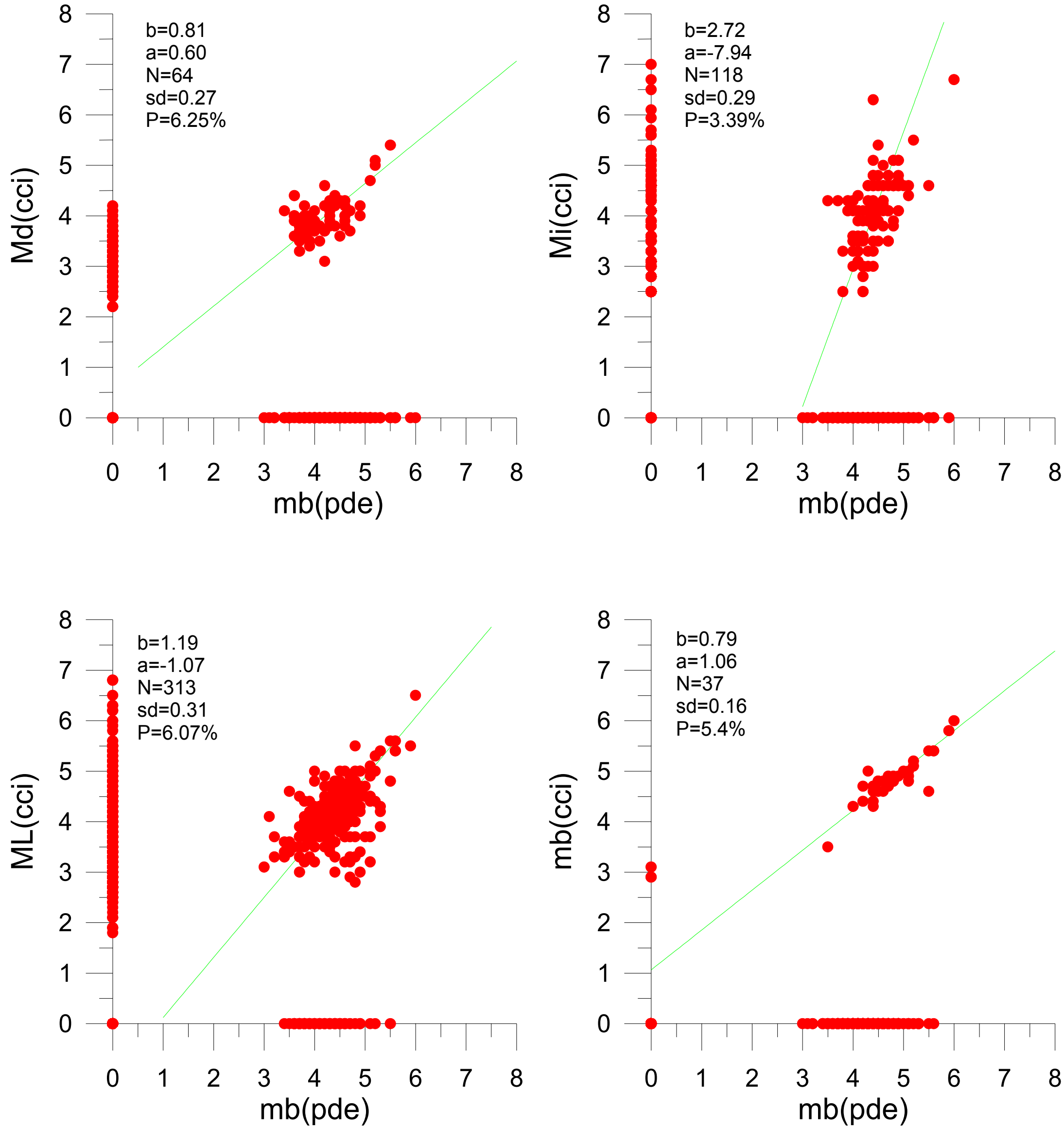

b=0.81
a=0.60
N=64
sd=0.27
P=6.25%
Md(cci)
mb(pde)
b=2.72
a=-7.94
N=118
sd=0.29
P=3.39%
Mi(cci)
mb(pde)
b=1.19
a=-1.07
N=313
sd=0.31
P=6.07%
ML(cci)
mb(pde)
b=0.79
a=1.06
N=37
sd=0.16
P=5.4%
mb(cci)
mb(pde)

Fig. 4a

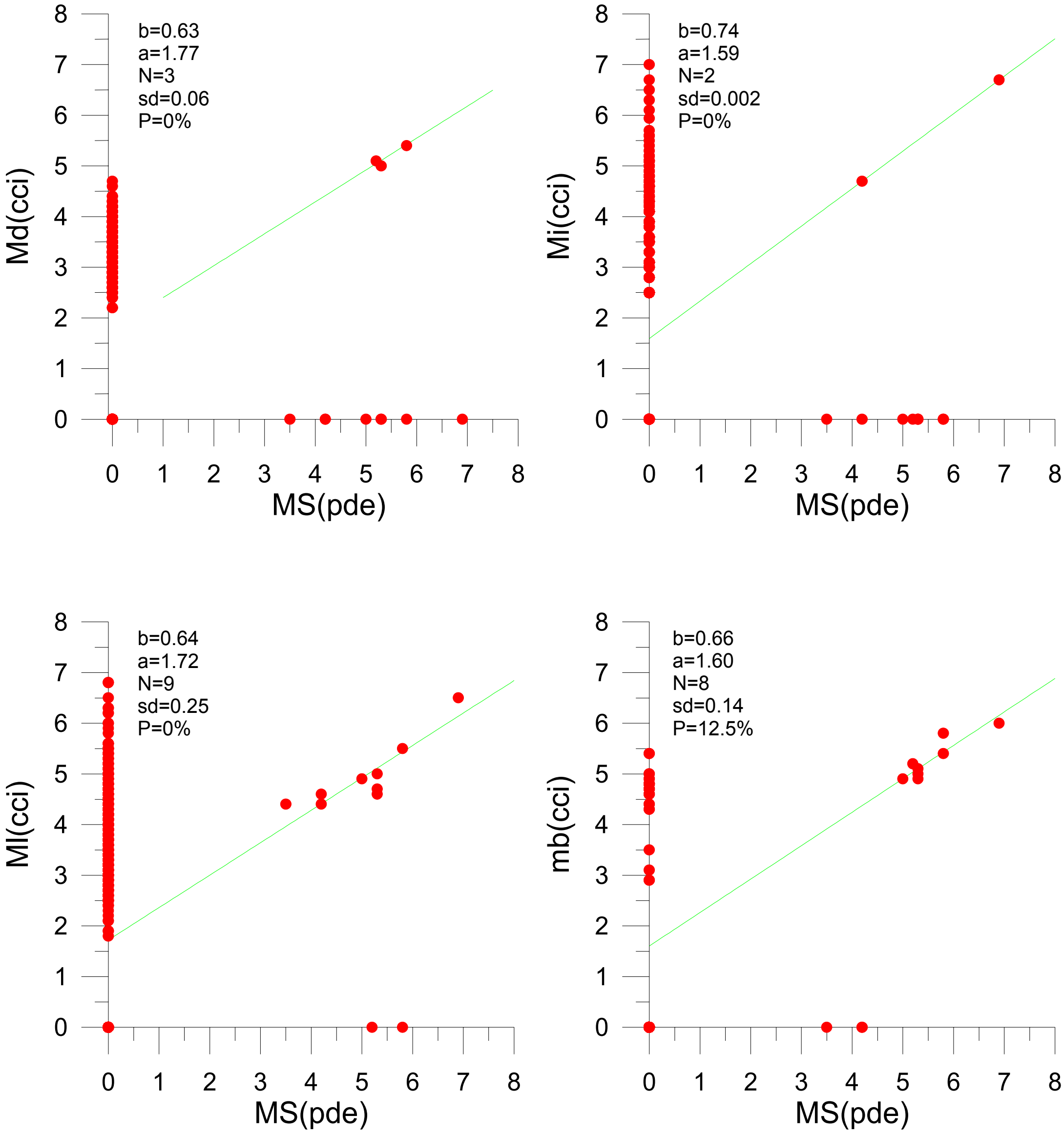

b=0.63
a=1.77
N=3
sd=0.06
P=0%
Md(cci)
MS(pde)
b=0.74
a=1.59
N=2
sd=0.002
P=0%
Mi(cci)
MS(pde)
b=0.64
a=1.72
N=9
sd=0.25
P=0%
Ml(cci)
MS(pde)
b=0.66
a=1.60
N=8
sd=0.14
P=12.5%
mb(cci)
MS(pde)

Fig. 4b

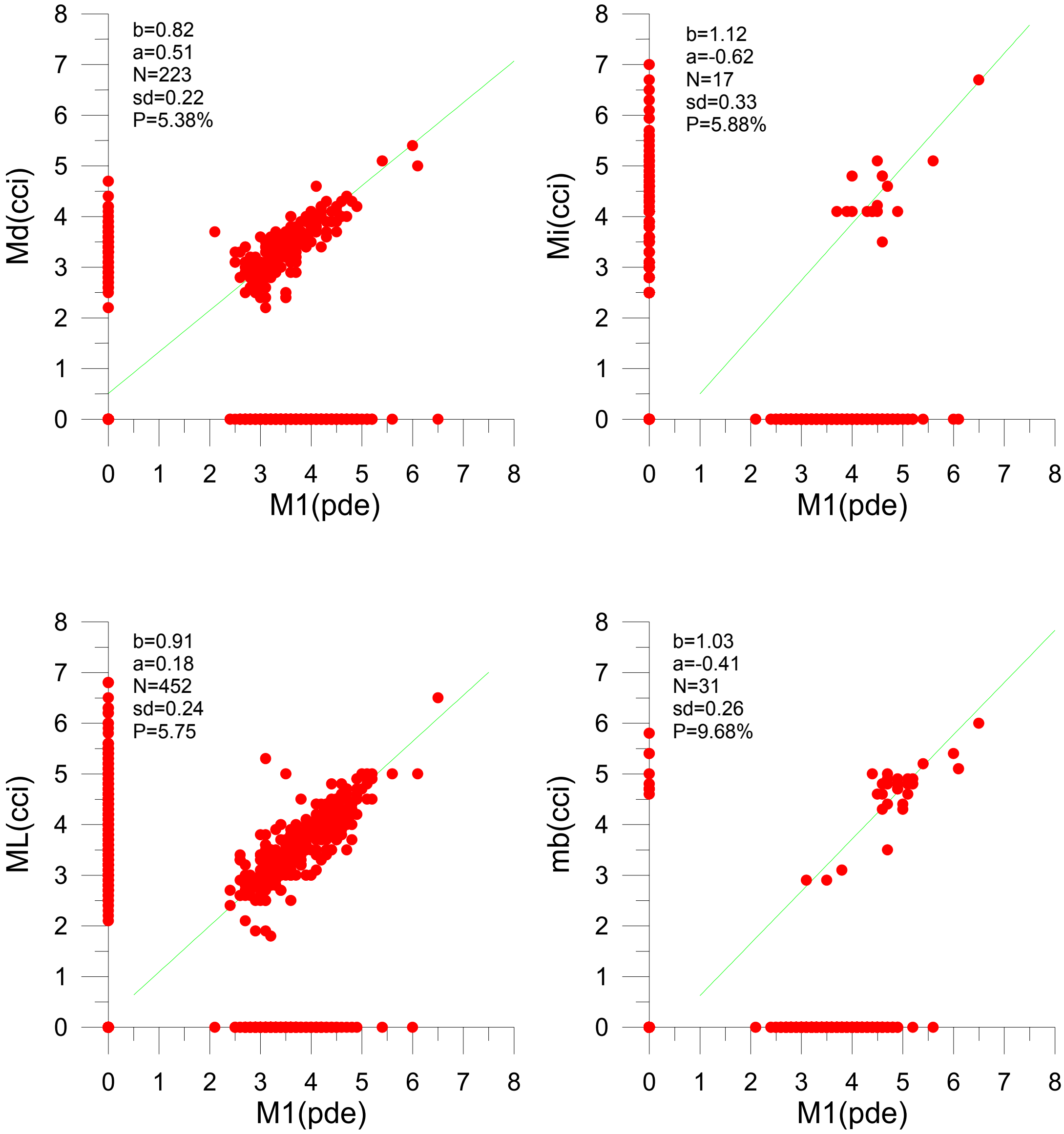
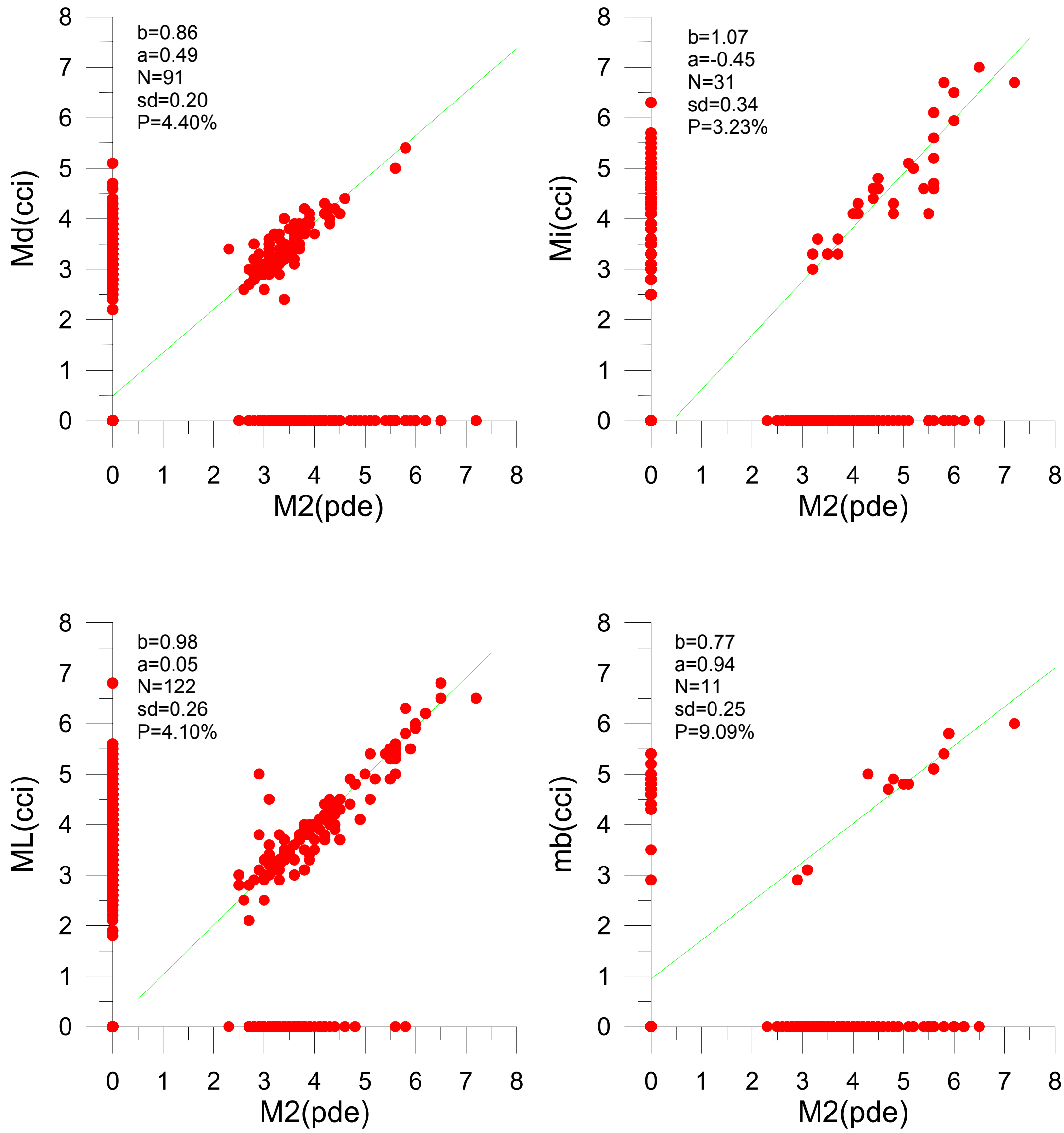
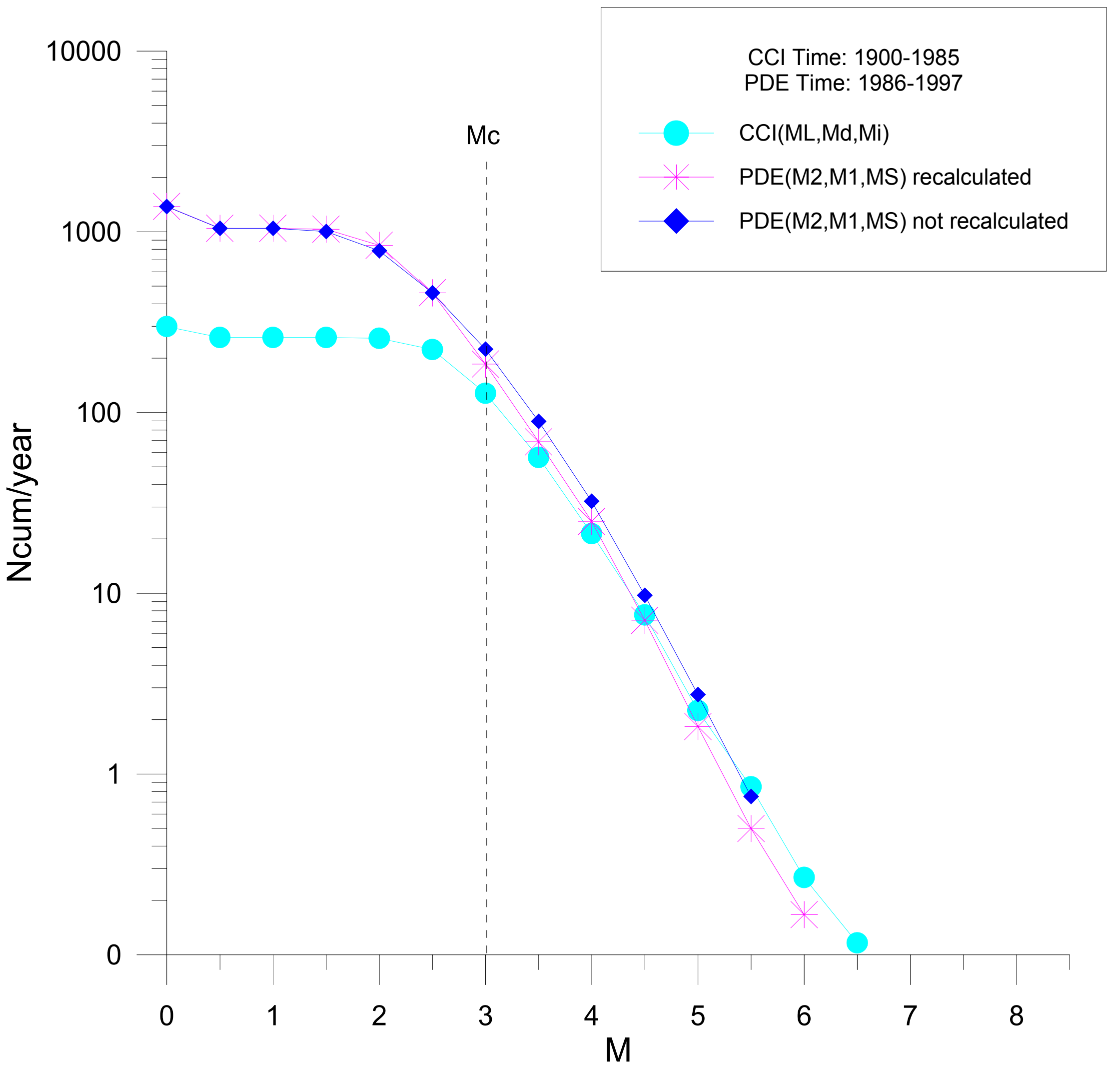

b=0.82
a=0.51
N=223
sd=0.22
P=5.38%
Md(cci)
M1(pde)
b=1.12
a=-0.62
N=17
sd=0.33
P=5.88%
Mi(cci)
M1(pde)
b=0.91
a=0.18
N=452
sd=0.24
P=5.75
ML(cci)
M1(pde)
b=1.03
a=-0.41
N=31
sd=0.26
P=9.68%
mb(cci)
M1(pde)

Fig. 4c



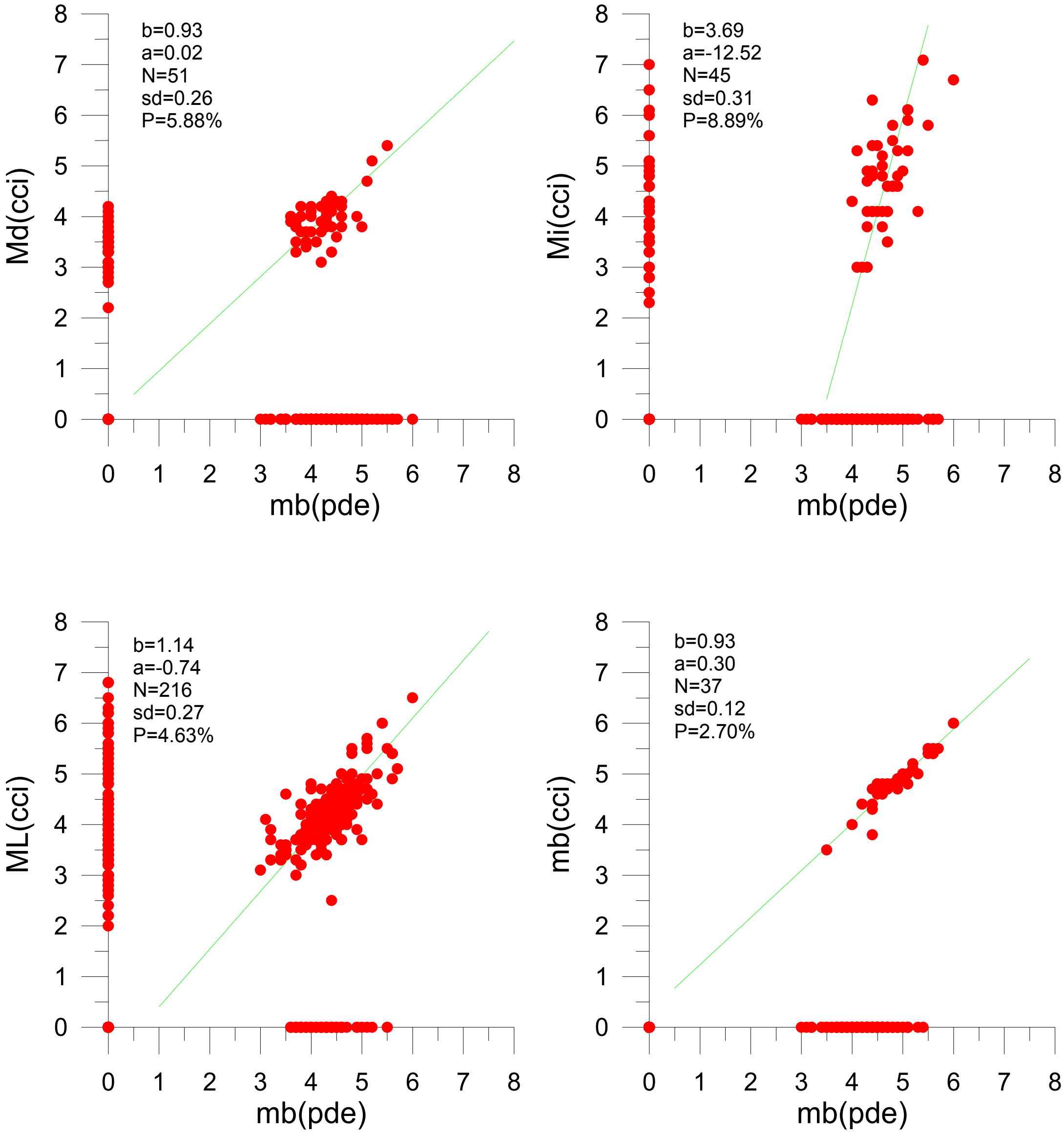
b=0.86
a=0.49
N=91
sd=0.20
P=4.40%
Md(cci)
M2(pde)
b=1.07
a=-0.45
N=31
sd=0.34
P=3.23%
Mi(cci)
M2(pde)
b=0.98
a=0.05
N=122
sd=0.26
P=4.10%
ML(cci)
M2(pde)
b=0.77
a=0.94
N=11
sd=0.25
P=9.09%
mb(cci)
M2(pde)

Fig. 4d



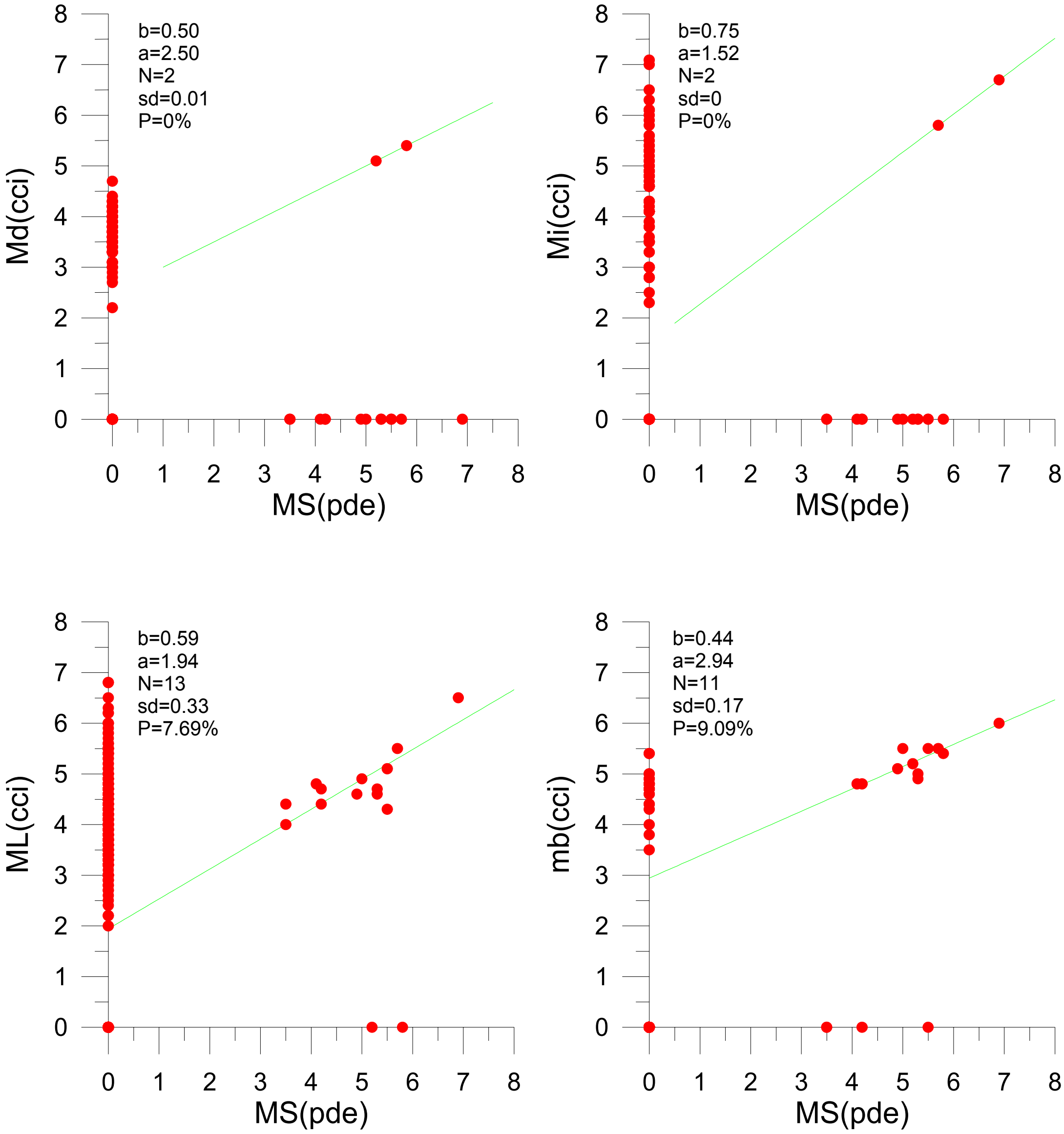
CCI Time: 1900-1985
PDE Time: 1986-1997
CCI(ML,Md,Mi)
PDE(M2,M1,MS) recalculated
PDE(M2,M1,MS) not recalculated
Mc
10000
1000
100
10
1
0
Ncum/year
0
1
2
3
4
5
6
7
8
M

Fig. 5



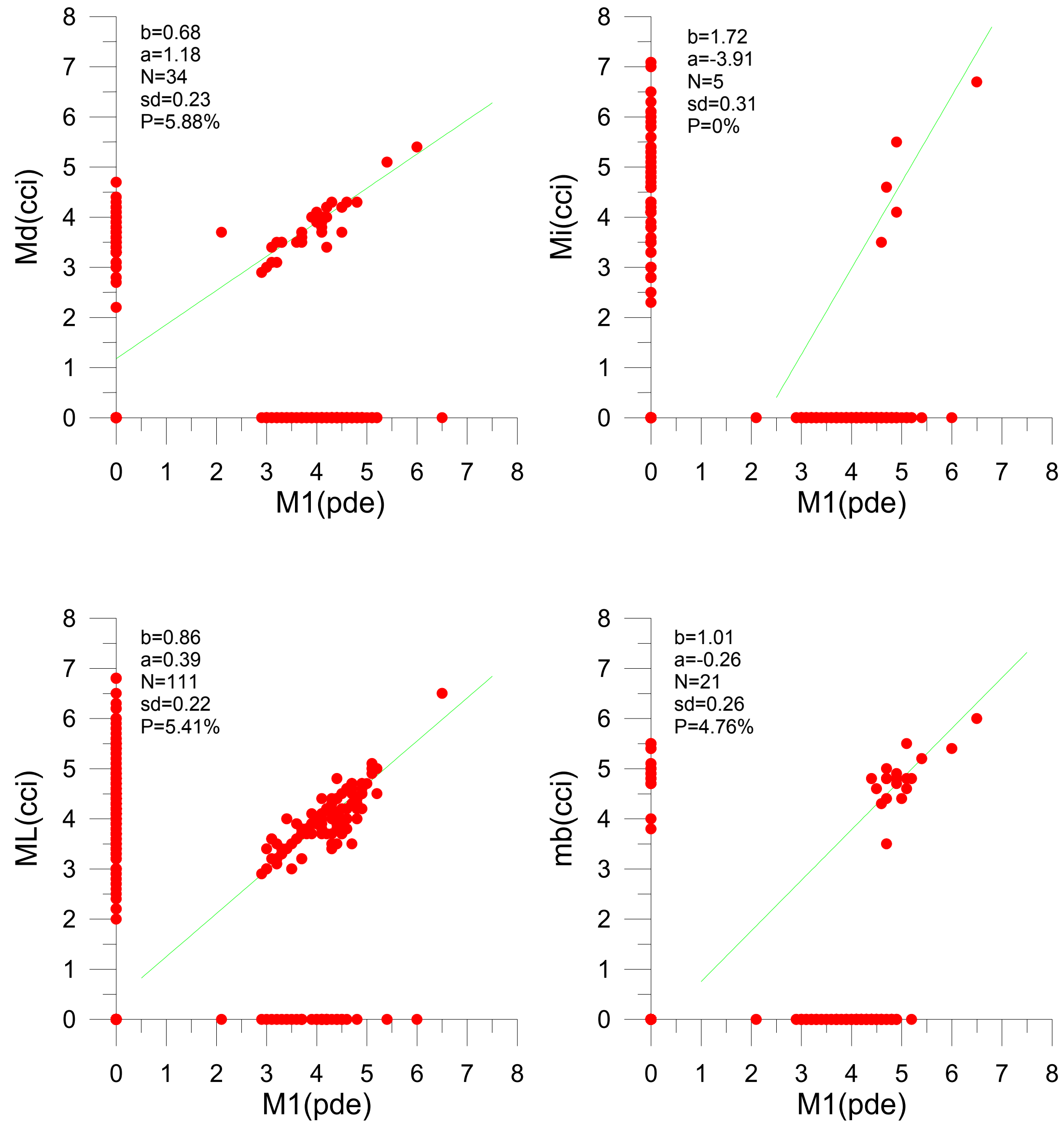
b=0.93
a=0.02
N=51
sd=0.26
P=5.88%
Md(cci)
mb(pde)
b=3.69
a=-12.52
N=45
sd=0.31
P=8.89%
Mi(cci)
mb(pde)
b=1.14
a=-0.74
N=216
sd=0.27
P=4.63%
ML(cci)
mb(pde)
b=0.93
a=0.30
N=37
sd=0.12
P=2.70%
mb(cci)
mb(pde)

Fig. 6a



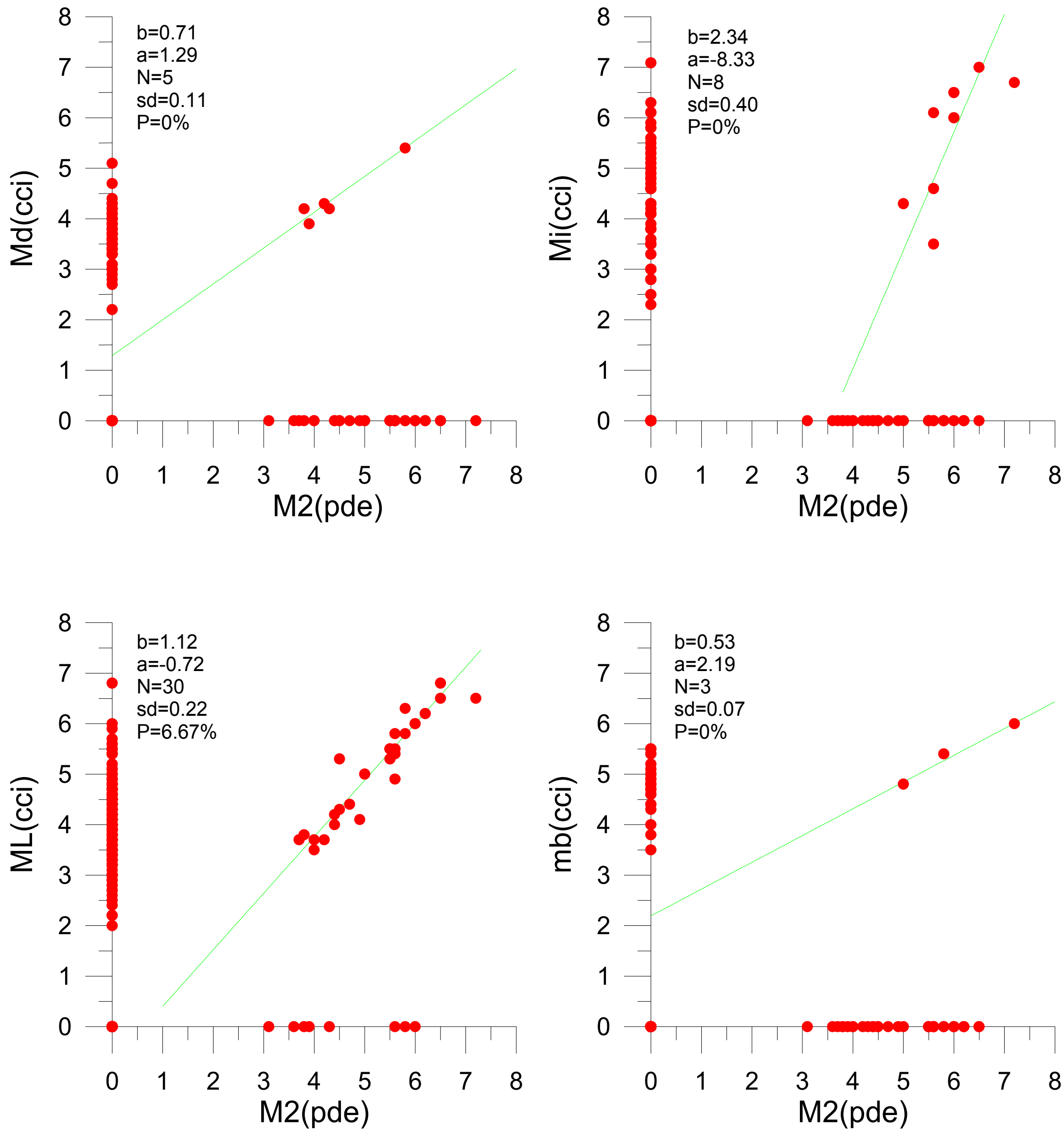
b=0.50
a=2.50
N=2
sd=0.01
P=0%
Md(cci)
MS(pde)
b=0.75
a=1.52
N=2
sd=0
P=0%
Ml(cci)
MS(pde)
b=0.59
a=1.94
N=13
sd=0.33
P=7.69%
ML(cci)
MS(pde)
b=0.44
a=2.94
N=11
sd=0.17
P=9.09%
mb(cci)
MS(pde)

Fig. 6b



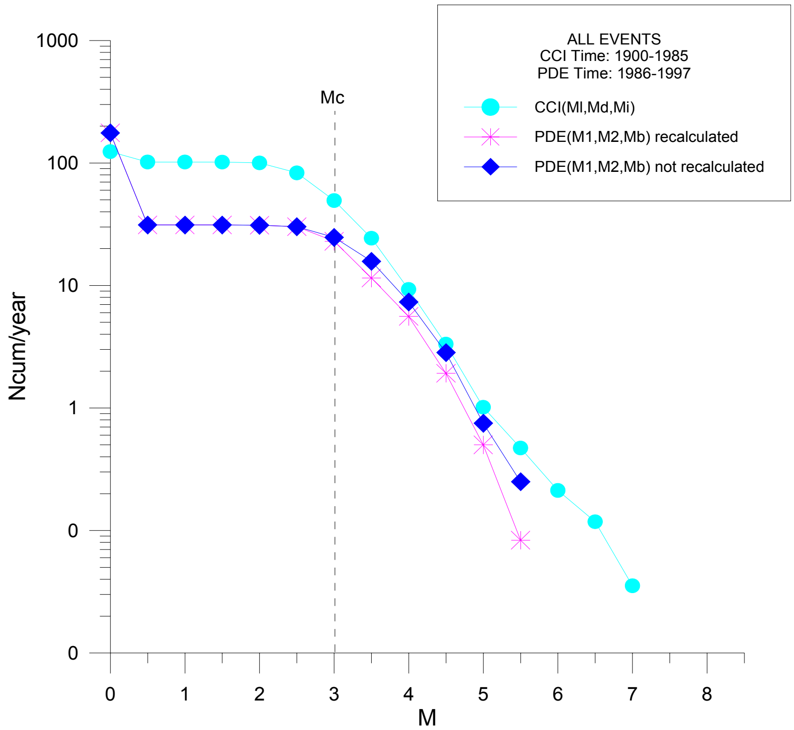
b=0.68
a=1.18
N=34
sd=0.23
P=5.88%
Md(cci)
M1(pde)
b=1.72
a=-3.91
N=5
sd=0.31
P=0%
Ml(cci)
M1(pde)
b=0.86
a=0.39
N=111
sd=0.22
P=5.41%
ML(cci)
M1(pde)
b=1.01
a=-0.26
N=21
sd=0.26
P=4.76%
mb(cci)
M1(pde)

Fig. 6c



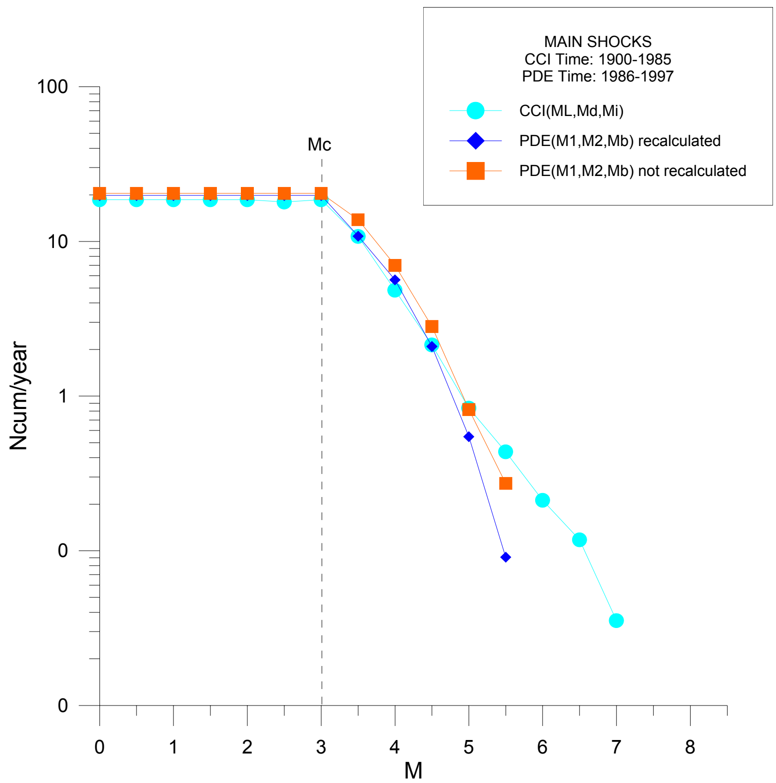
b=0.71
a=1.29
N=5
sd=0.11
P=0%
Md(cci)
M2(pde)
b=2.34
a=-8.33
N=8
sd=0.40
P=0%
MI(cci)
M2(pde)
b=1.12
a=-0.72
N=30
sd=0.22
P=6.67%
ML(cci)
M2(pde)
b=0.53
a=2.19
N=3
sd=0.07
P=0%
mb(cci)
M2(pde)

Fig. 6d



ALL EVENTS
CCI Time: 1900-1985
PDE Time: 1986-1997
CCI(Ml,Md,Mi)
PDE(M1,M2,Mb) recalculated
PDE(M1,M2,Mb) not recalculated
Mc
Ncum/year
M

Fig. 7a



MAIN SHOCKS
CCI Time: 1900-1985
PDE Time: 1986-1997
CCI(ML,Md,Mi)
PDE(M1,M2,Mb) recalculated
PDE(M1,M2,Mb) not recalculated
Mc
Ncum/year
M

Fig. 7b

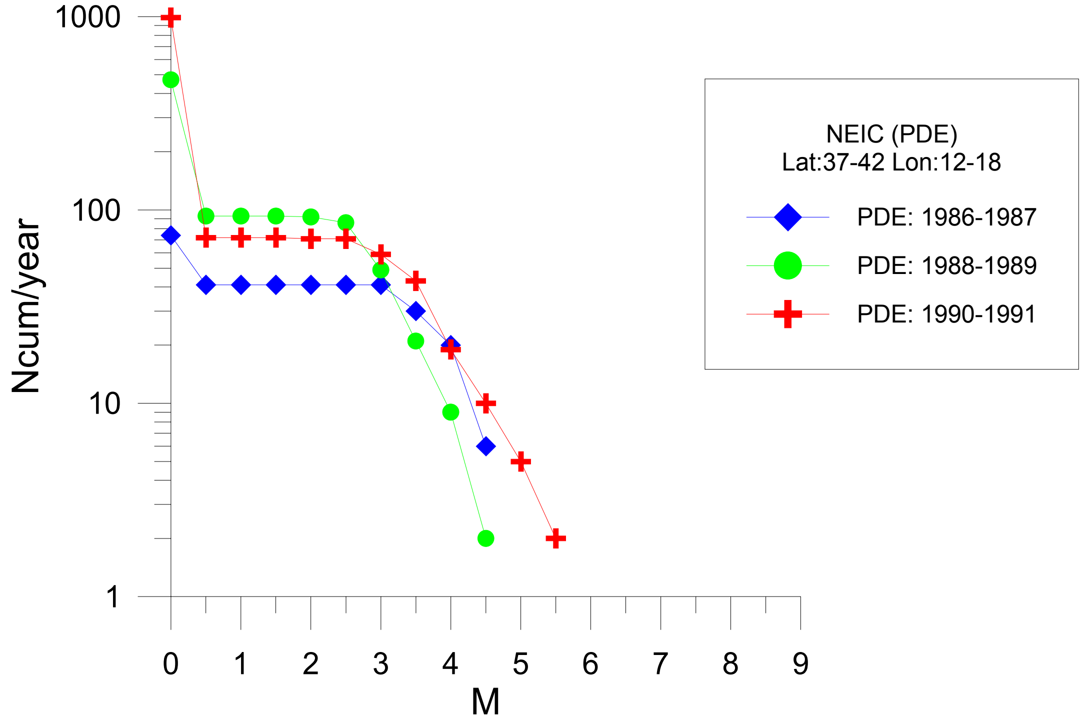

1000
100
10
1
Ncum/year
0
1
2
3
4
5
6
7
8
9
M
NEIC (PDE)
Lat:37-42 Lon:12-18
PDE: 1986-1987
PDE: 1988-1989
PDE: 1990-1991

Fig. 8a

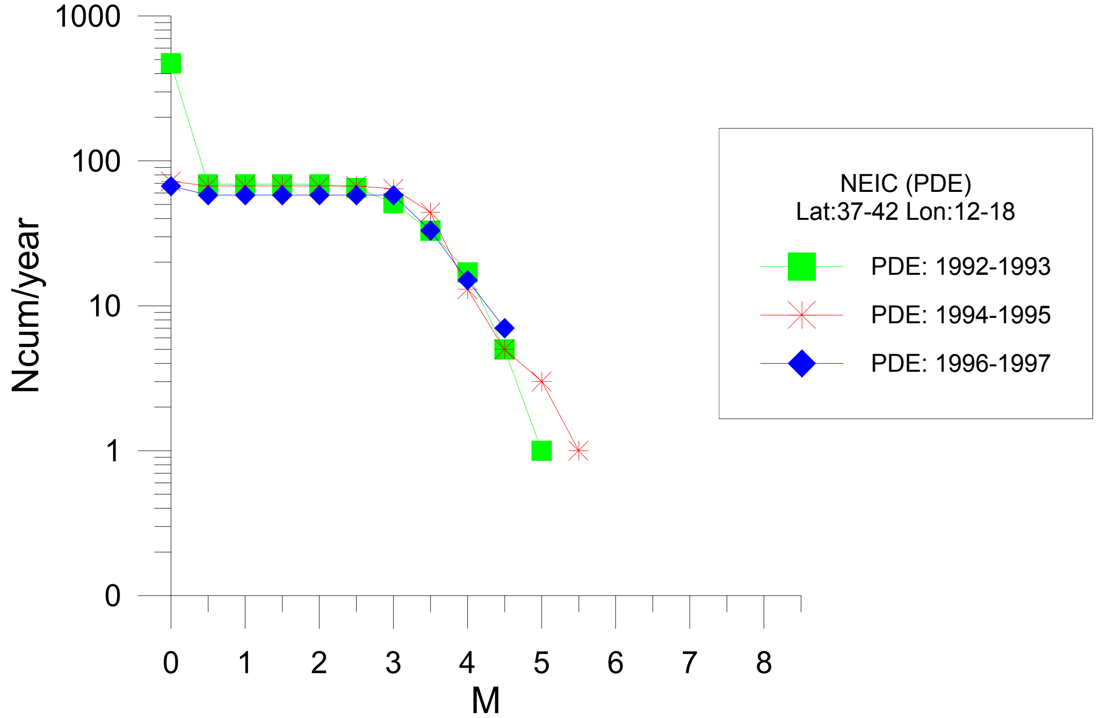

1000
100
10
1
0
Ncum/year
0
1
2
3
4
5
6
7
8
M
NEIC (PDE)
Lat:37-42 Lon:12-18
PDE: 1992-1993
PDE: 1994-1995
PDE: 1996-1997

Fig. 8b

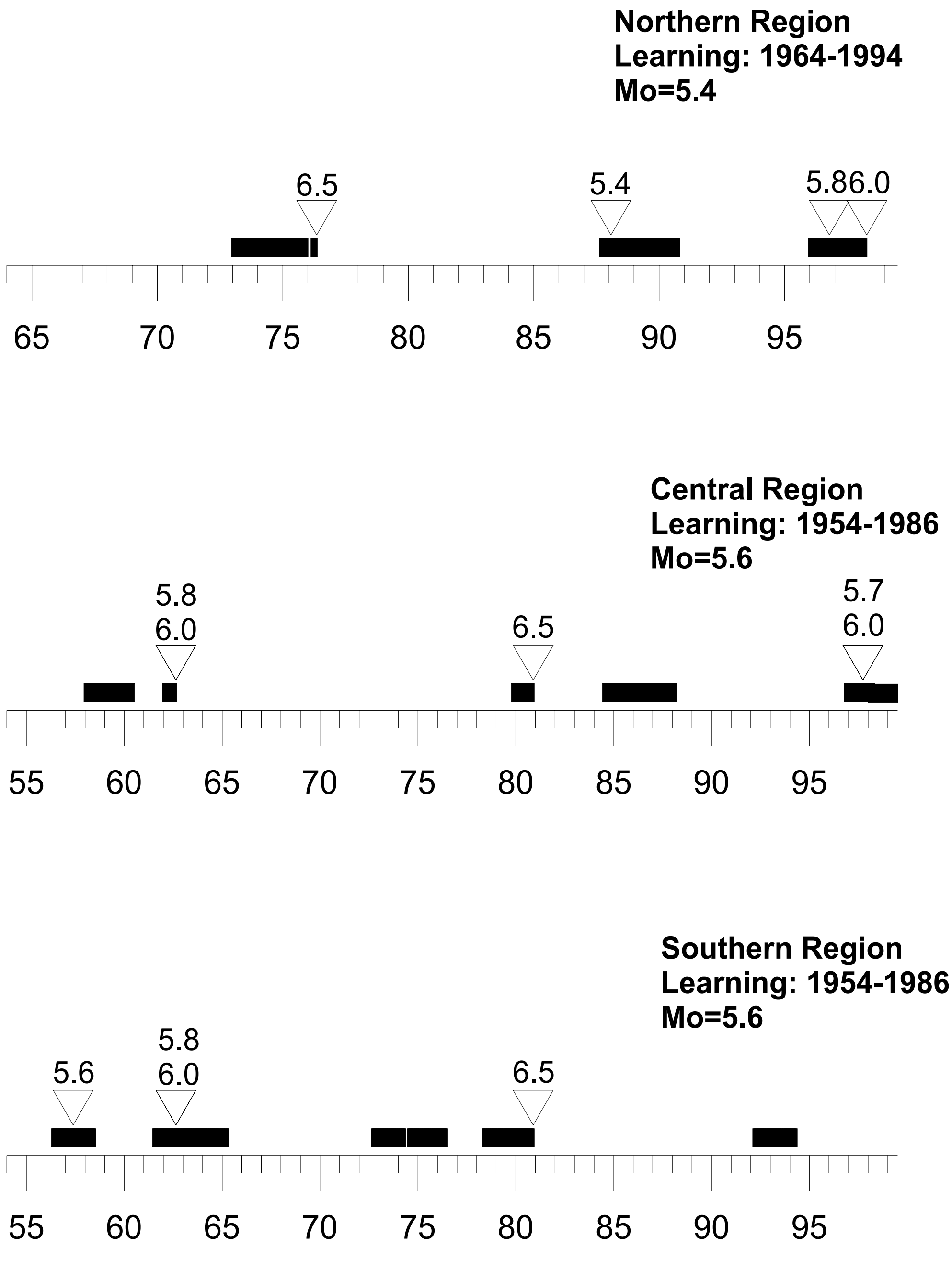

Northern Region
Learning: 1964-1994
Mo=5.4
6.5
5.4
5.8
6.0
65
70
75
80
85
90
95
Central Region
Learning: 1954-1986
Mo=5.6
5.8
6.0
6.5
5.7
6.0
55
60
65
70
75
80
85
90
95
Southern Region
Learning: 1954-1986
Mo=5.6
5.6
5.8
6.0
6.5
55
60
65
70
75
80
85
90
95

Fig. 9