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ANALYSIS OF EARTHQUAKE CATALOGUES FOR CSEP TESTING REGION ITALY

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ANALYSIS OF EARTHQUAKE CATALOGUES FOR CSEP TESTING REGION ITALY

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Abstract

A detailed analysis of the instrumental seismic catalogues provided by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), as the authoritative database for earthquake prediction experiment in the framework of the Collaboratory for the Study of Earthquake Predictability - Testing Region Italy (CSEP-TRI), has been carried out to evaluate their homogeneity and completeness. The capability of the considered input data to provide a consistent picture of seismic activity is, in fact, a necessary pre-requisite in view of a reliable prospective testing of different prediction/forecast methods.

The different INGV data sets, which are proposed for CSEP models development and testing, turn out to be significantly heterogeneous over space and time, as demonstrated by the comparative analysis performed amongst the various data parts as well as with the global NEIC (PDE) data. Specifically, the CSI1.1 catalogue, despite of its recent revision (*Castello et al., 2007*), appears affected by a relevant magnitude underestimation with respect to NEIC; the average magnitude difference in the period 1986-2002 is around 0.5, which is well comparable to that evidenced so far by *Peresan et al. (2000)* and confirmed by *Gasperini et al. (2001)* considering an earlier version of the INGV data. The evidenced inconsistency of magnitude estimations is substantiated by the cross-comparison of the different INGV data sets, particularly during the year 2002, when both the CSI1.1 catalogue and instrumental bulletins are available. The most recent INGV data set, namely BSI bulletins compiled since April 2005, is in better agreement with the NEIC data and it is eventually characterised by quite a high completeness level, especially in peninsular Italy. Nevertheless, due to its very short time span, it still does not allow for a representative description of Italian seismicity, especially at intermediate-term time scale.

The spatial homogeneity of completeness in INGV data, as well as the changes in territorial completeness at the transition from one data set to the subsequent one, have been investigated following two different approaches, one based on *pddf* (probability density distribution functions) of earthquake epicentres and the other on the ratio of common events, using the NEIC catalogue as the reference data set. The analysis evidenced a relative deficiency of the INGV data in the north of CSEP-TRI, in comparison with the NEIC data. Moreover, a remarkable spatial heterogeneity of completeness of the INGV data is detected in the period from 1986 to 2002, indicating a deficiency of the CSI1.1 data mainly in the north (above 43°N), and a comparatively high rate of seismic events to the south (particularly Sicily), with respect to NEIC.

We have thus to conclude that the catalogues provided by INGV as the authoritative database for CSEP-TRI is hardly a unified one acceptable for the necessary tuning of models/algorithms, as well as for running any rigorous prospective predictability test.

1. Introduction

This study aims to a detailed analysis of the instrumental seismic data recommended for models development and testing in the framework of the Collaboratory for the Study of Earthquake Predictability (CSEP), Test Region Italy (TRI), specifically the earthquake bulletins and catalogues compiled at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) since 1981. The rationale for this analysis consists in the preliminary assessment of the reliability of the considered input data in providing a consistent picture of seismic activity over space and time that is a necessary pre-requisite in view of a reliable prospective testing of different prediction/forecast methods.

According to the *Rules of the Game* (http://eu.cseptesting.org/Documents) for CSEP-TRI testing, the collection and testing areas are predefined, based on a specified spatial grid (http://eu.cseptesting.org/TestingRegionItalyDocuments). Only earthquakes with depth less than 30 km are considered. The INGV local magnitude scale *ML* is announced as the reference scale for models development and testing. The prospective tests (i.e. the updating of forecasts/predictions results) are performed “with a delay of 30 days relative to real-time, in order for the authoritative data to be manually revised and published”.

The seismic catalogues provided for forecast/prediction modellers as the authoritative database for the first testing region within Europe of CSEP, EU Testing Center (http://eu.cseptesting.org/TestingRegionItaly) are the following

(http://eu.cseptesting.org/TestingRegionItalyCatalogs):

1) CPTI08 (Catalogo Parametrico dei Terremoti Italiani) from 1901 to 2006. (http://www.cseptesting.org/regions/italy);
2) CSI.1.1 (Catalogo della Sismicità Italiana) from 1981 to 2002 (http://csi.rm.ingv.it/);
3) BSI (Bollettino Sismico Italiano), Authoritative Data Source, since 16 April 2005 (available up to March 2009 as half-month data chunks at http://bollettinosismico.rm.ingv.it/, and up to present day through interactive search at
4) http://iside.rm.ingv.it/iside/standard/result.jsp?rst=1&page=EVENTS).

The Italian Seismic Bulletin, BSI, is the official earthquake catalogue of CSEP-TRI against which forecasts and predictions will be evaluated. It is announced as the authoritative data source, while the other two catalogues are suggested as supplementary ones.

5) ISIDE (Italian Seismic Instrumental and parametric Data-basE), from January 2002 to April 15, 2005 (http://bollettinosismico.rm.ingv.it/). This part of the Italian seismic bulletin, spanning the time interval between CSI1.1 and BSI, is also available as half-month data chunks, though reported under revision (*Christophersen et al., 2009*).

To what extent can the enlisted data be used for space-time analysis of seismicity in Italy? To answer this question we analyse homogeneity and completeness of the INGV earthquake data provided for the CSEP-TRI for the period 1981 – June 25, 2009, referred hereinafter as INGV/CSEP catalogues. Special attention is paid to the consistency among the different data sets making up the INGV/CSEP catalogues, as well as to their consistency with the global catalogue NEIC (*GHDB, 1989*), that is currently used for the on-going (since about six years) real-time earthquake prediction experiment in Italy (*Peresan et al., 2005*).

Recently *Christophersen et al. (2009)* have studied the CPTI08 (1) and CSI.1.1 (2) catalogues and for CPTI08 (*Rovida et al., 2008*) they determine the completeness magnitude threshold *Mc*=4.8, which is evidently not suitable for the application of forecast/prediction methodologies based on the analysis of the variability of seismicity at low magnitude ranges, like those already in use (*Peresan et al., 2005*). Moreover, the CPTI08 catalogue is not suitable for the analysis of premonitory seimicity patterns, since it reports only mainshocks with some of the foreshocks and aftershocks (*Rovida et al., 2008*). That is why here we analyse the datasets (2), (3), and (4) only.

2. General completeness and homogeneity analysis

2.1. CSI1.1 catalogue, 1981 – 2002

There are 91797 earthquakes in the CSI1.1 dataset. We consider only those having specified magnitude determinations: 39665 events with locations between 35.16^0 - 48.6^0N and 4.85^0 – 22.0^0E, depth from 0 to 483 km, with the largest magnitude M=5.9. Every earthquake in the catalogue holds a single magnitude determination, nevertheless the magnitude estimate can be of different type. The local magnitude type *ML* estimated from duration is the predominant one; it is assigned to 81.9% of all events and is present in 1983-2002. Besides, part of the events is assigned *ML* taken fromthe CSTI1.0 Catalogue (1.6% of all events), in 1981-1995, or *ML* from Mediterranean Network MedNet (16.2%), in 1996-2002. For a few sparse deep earthquakes the magnitude type is either *mb* or *Mw* (0.3%). The shallow earthquakes, with magnitude 4.0 and larger, are assigned either *ML* from CSTI1.0 or *ML* from Mediterranean Network, depending on the origin time, while the *ML* estimated from duration is provided only for 18% of the events. Thus the proportion of magnitude types is not uniform for small and large earthquakes.

To gain a general insight about catalogue completeness and stability a useful technique is to plot earthquake magnitude (Fig.1) and depth (Fig.2) against the origin time. In Fig. 1 one can observe, for example, very poor registration of earthquakes in 1981-1982, which eventually becomes a little bit better in 1983. In 1981-1995 there are almost no earthquakes with magnitude below 1.5; afterwards there are a few, but the data remain evidently incomplete. The great difference of the density between depths in the range 0-35 km and larger depths is observable in Fig.2. In the period from 1981 to 1984 there are almost no earthquakes deeper than 35 km.

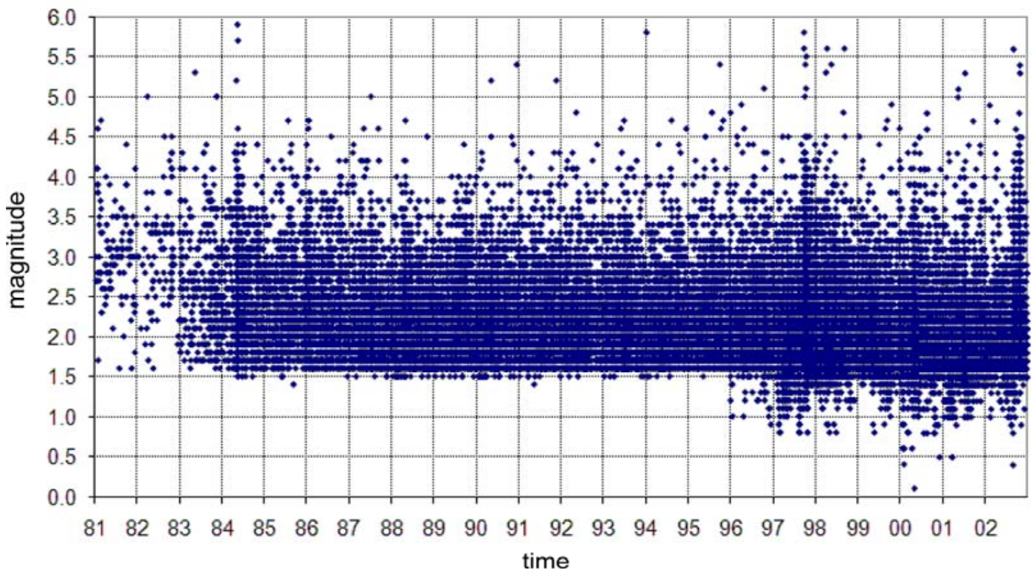


Figure 1. Magnitude versus origin time: CSI1.1 catalogue.

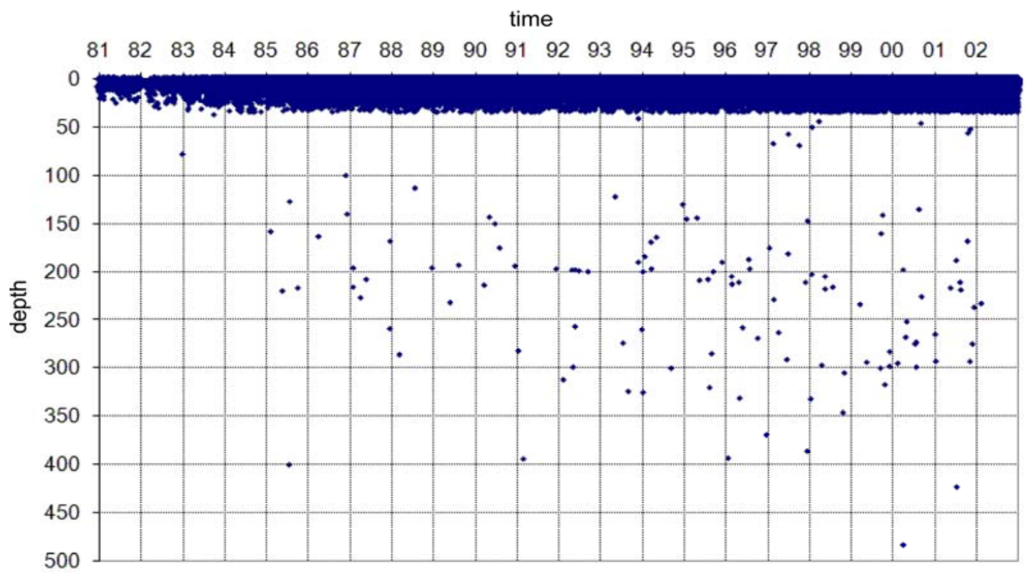


Figure 2. Depth versus origin time: CSI1.1 catalogue.

The distribution of number of events versus depth (Fig. 3) confirms the preliminary observation that the overwhelming majority of events in CSI1.1 has depth 35 km or shallower (99.7% of all records). The most frequent depths, except zero, are around 6 km (about 12%) a depth that is likely to be related with the properties of the hypocentres location procedure. The sharp bound at 35 km depth looks like an artefact of similar origin and does not coincide with the 30 km fixed for the authoritative CSEP-TRI selection.

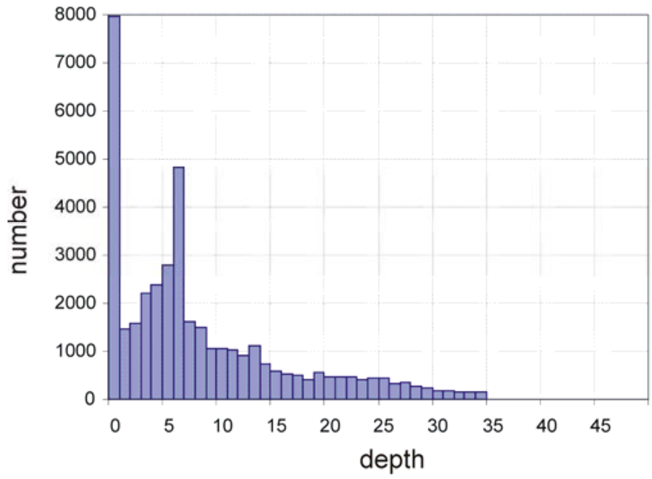


Figure 3. Frequency-depth histogram: CSI1.1 catalogue, depths 0-50 km.

The authoritative CSEP-TRI data in 1981-2002 consist of a selection of earthquakes from CSI1.1 catalogue, including only events within the predefined data collection area and with a depth lower bound at 30 km (http://eu.cseptesting.org/TestingRegionItalyCatalogs). More than 97% of CSI1.1 earthquakes with reported magnitude are included in the authoritative CSEP-TRI data selection. The following problem with depth has been detected in the CSEP-TRI data selection: 38 earthquakes from CSI1.1 catalogue, with the original depths within ranges 100-130, 200-230, 300-330, and 400-430, are reported with incorrect values of depth. The error most likely occurred at the stage of format conversion, due to an error in the CSI1.1 format description (http://csi.rm.ingv.it/catalogo/doc11/sum.htm). These 38 events have been excluded from further analysis.

Fig. 4 displays the temporal evolution of the semi-annual number of earthquakes above different magnitude thresholds in CSEP-TRI selection of the CSI1.1 catalogue. The ordinate is given in logarithmic scale, in accordance with the Gutenberg-Richter relation, so that a near-uniform distance between adjacent curves implies an exponential distribution of earthquakes in the catalogue. This graphical approach appears effective in providing preliminary information on catalogue completeness and homogeneity. It allows us to identify periods during which the catalogue is evidently incomplete, possible gaps, drops and gradual changes in the registration level, as well as magnitude ranges that are obviously incomplete. The changes with time in the definition of the magnitude scale, which may bias the frequency-magnitude distribution, can be detected from this graph too. Surely the visual inspection does deliver precise determination of the completeness level, but allows the selection of the periods of data homogeneity for further detailed analysis. The distribution of the number of earthquakes versus time and magnitude (Fig. 4) evidences that before 1984 the CSEP-TRI selection of CSI1.1 catalogue, is not complete up to magnitude 3.5 or even higher. From 1984 the level of completeness is about 3.0, from 1986 it is about 2.5, and after 1999 it approaches 2.0.

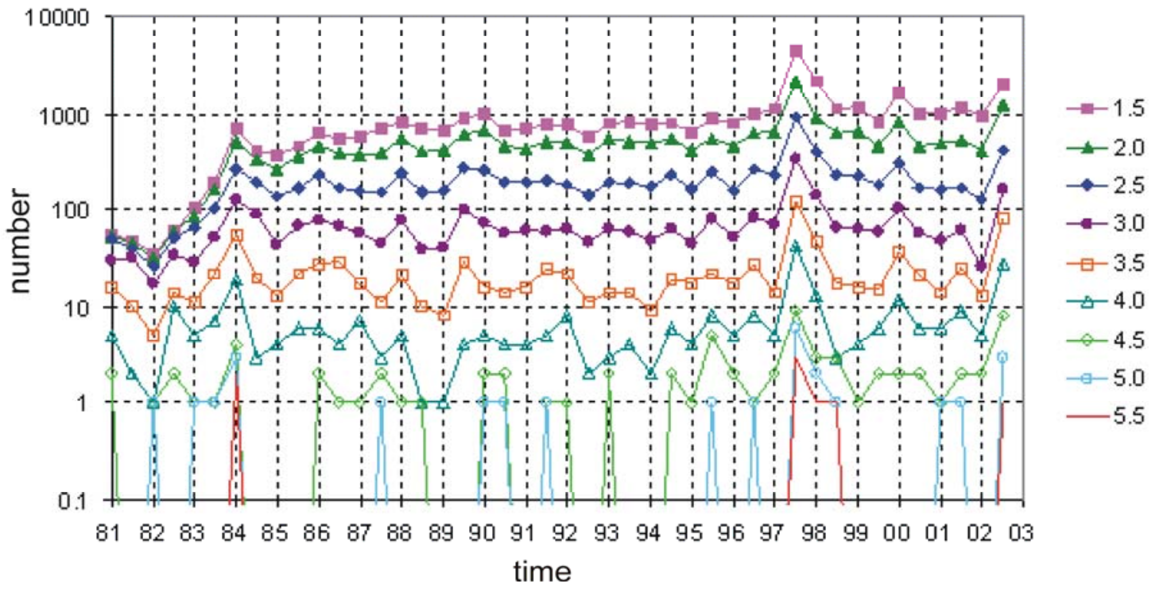


Figure 4. Semi-annual numbers of earthquakes above different magnitude thresholds: CSEP-TRI selection of CSI1.1 catalogue.

To verify our observation we plot the Gutenberg-Richter (G-R) graphs for three 3-year periods: two consecutive from the beginning of the catalogue and one from the end (Fig. 5). The figure shows that in 1981-1983 the magnitude of completeness of CSI1.1 is definitely above 3.0, and appears to be close to 4.0. In 1984-1986 the completeness is about 3.0, and in 2000-2002 it is about 2.0. Our conclusions disagree with the completeness magnitude threshold *Mc* given by *Christophersen et al., 2009* for CSI1.1 and indicate its essential underestimation, that results apparently from the *maximum curvature method* (*Woessner and Wiemer, 2005*) used by *Christophersen et al., 2009*. It is well known that the point of maximum curvature of the G-R curve may be considered as a crude estimate of the level of completeness *Mc*; however, it usually underestimates *Mc*, especially in the case of gradually curved G-R curve. No bootstrapping can prevent from this underestimation, therefore a correction should be added to *Mc*. For example, *Woessner and Wiemer, 2005* suggest to use *Mc* + 0.2 or even *Mc* + 0.5, depending on the catalogue. Such correction makes *Mc* values given by *Christophersen et al., 2009* quite consistent with our estimations.

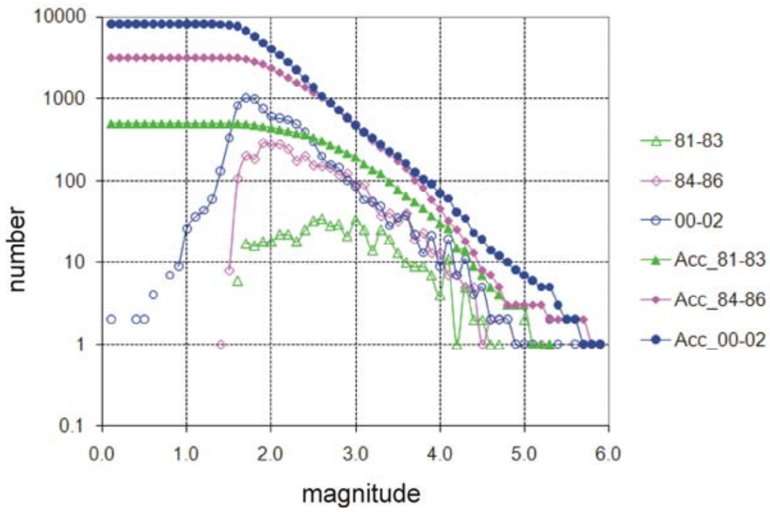


Figure 5. Frequency-magnitude histograms (empty markers – non-cumulative, filled markers - cumulative) of earthquakes in CSI1.1 catalogue, CSEP-TRI, for the selected 3-year periods: 1981-1983 (triangles), 1984-1986 (diamonds), and 2000-2002 (circles).

2.2. Italian Seismic Bulletin: January 1, 2002 – June 25, 2009

Seismic Bulletins are available at the INGV website in two entities, which cover overlapping time intervals and are presented in two different ASCII formats. The first one is referred to as ISIDE and is published as half-month data chunks for January 1, 2002 – March 31, 2009. The other one is BSI, available by means of interactive search tools, since April 16, 2005 up to the present. We consider ISIDE for the period 2002 to April 15, 2005, and BSI, since April 16, 2005 up to June 25, 2009. BSI is the authoritative earthquake catalogue of CSEP-TRI against which forecasts and predictions will be evaluated. For overlapping time interval (April 16, 2005 – March 31, 2009) BSI and ISIDE data are not identical. At the time of our analysis (July 2009) there are earthquakes in the BSI catalogue, which are absent in ISIDE and vice-versa, and some events have different magnitude values in the two data sets. Since these cases of inconsistency are sparse we use the data as they are in the periods determined above. ISIDE data contain an indication of magnitude type, which we use in our analysis for the whole time available.

There are 8031 earthquakes with reported magnitude in the ISIDE dataset; they are located between 34.25^0 - 47.81^0N and 5.33^0 – 23.36^0E and in the depth range from 0 to 534 km, the largest event having M=5.6. The reported magnitude estimates are not uniform. Every earthquake holds either local magnitude *ML* (only 2.1% of all events) or duration magnitude *MD* (overwhelming majority of events, 97.9%). For large earthquakes, however, *ML* magnitude type is predominant. For example, for earthquakes with magnitude M ≥ 3.5 the percentage of *ML* is nearly 55%, while for those with magnitude M ≥ 4.0 it is 89%.

The BSI dataset includes 33484 earthquakes with reported magnitude; they are located between 34.00^0 - 48.13^0N and 5.28^0 – 24.00^0E, in the depth range from 0 to 502 km, the largest event having M=5.8. The magnitude presented is either local *ML* (96.5% of all events up to March 31, 2009; after this date the information about magnitude type is not available) or duration magnitude *MD* (3.5% of all events up to March 31, 2009). Magnitude *MD* is given mostly for small earthquakes; more than 98% of the *MD* estimates does not exceed 3.0.

Thus, the predominant magnitude type in ISIDE database is *MD* for small and moderate earthquakes and *ML* for large events, while in BSI the predominant magnitude is *ML* in the entire magnitude range. Therefore, the natural question arises: how can ISIDE data be used for forecast/prediction models development within CSEP project, if the INGV *ML* magnitude scale is declared as the only reference scale for model development and testing (*Rules of the Game*)? In spite of this inconsistency, we analyse Italian Seismic Bulletins, both the ISIDE and BSI, because there is no other INGV/CSEP instrumental dataset provided for the period from 2003 to April 15, 2005 with comparable level of completeness.

From the plots in Figures 6 and 7 (similar to Figures 1, 2) one can observe that the quality of Italian seismic bulletins before and after April 16, 2005 is actually different. Differences concern the level of detection (changing from about 2.0 in ISIDE to about 0.5 in BSI), the depth lower limit for shallow events (from about 30 km in ISIDE to about 40 km in BSI) and the overall increase in the number of intermediate and deep events.

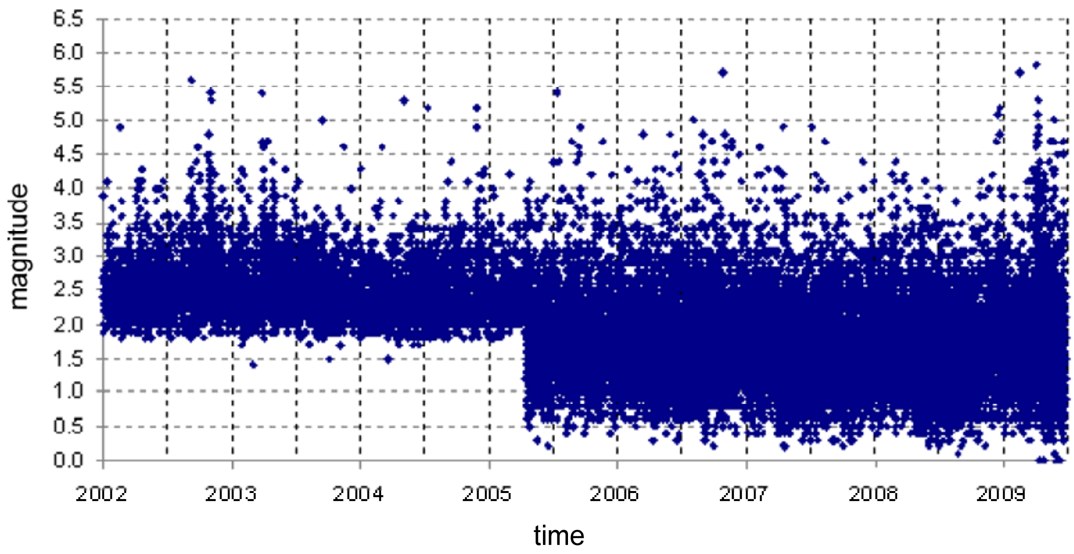


Figure 6. Magnitude versus origin time plot of earthquakes in ISIDE, 2002 – April 15, 2005, and BSI, April 16, 2005 – June 25, 2009, bulletins.

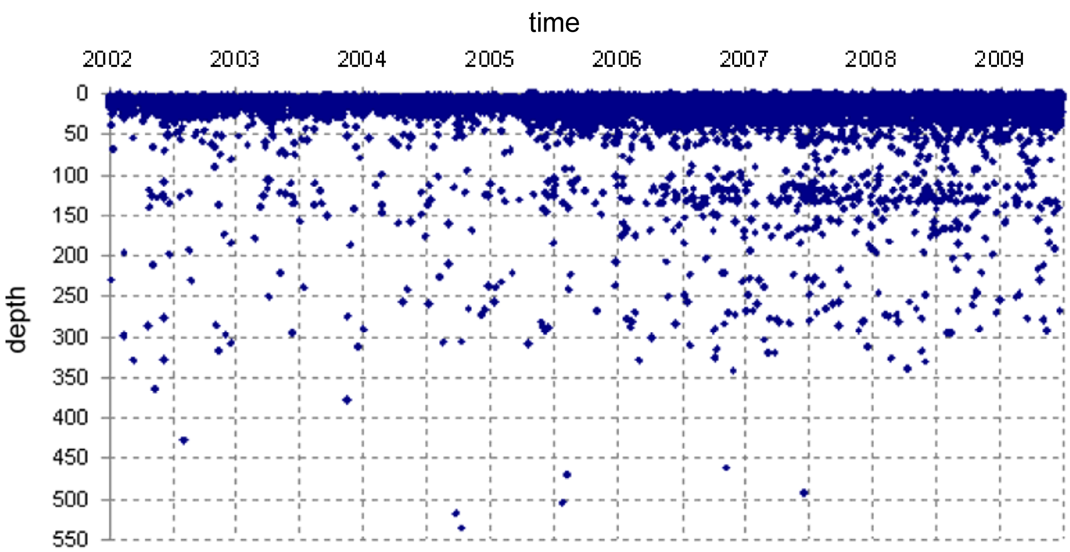


Figure 7. Depth versus origin time plot of earthquakes in ISIDE, 2002 – April 15, 2005, and BSI, April 16, 2005 – June 25, 2009, bulletins.

From the frequency-depth histogram of the earthquakes reported in ISIDE and BSI catalogues, for focal depths in the range from 0 to 50 km (Fig. 8), one can see that the overwhelming majority of events have depth ≤ 30 km, both in ISIDE (97.6%) and in BSI (96.3%). There are two, apparently artificial, predominant depths in ISIDE, namely 5 km (26% of all events) and 10 km (39%). The predominant depth in BSI is around 10 km (30%). The shallow earthquake distribution in both ISIDE and BSI (Fig. 8) differ significantly from that in CSI1.1 catalogue (Fig. 3), and this fact implies that detailed information on depth is hardly an acceptable requirement for seismicity modelling.

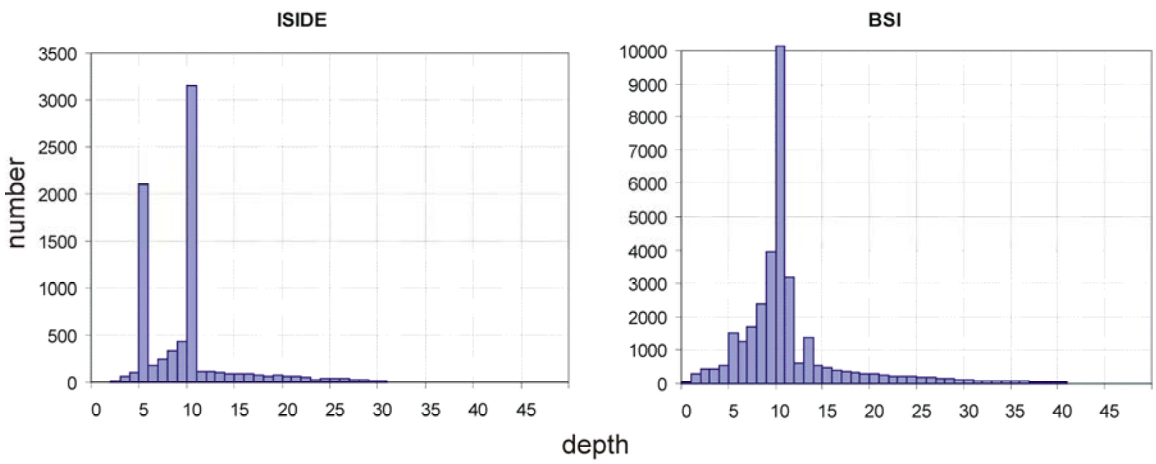


Figure 8. Frequency-depth histogram of earthquakes in ISIDE and BSI catalogues, depths 0-50 km.

More than 95% of ISIDE and BSI earthquakes are included in the CSEP-TRI data collection area and depth range. Figure 9 displays the temporal evolution of the semi-annual number of earthquakes above different magnitude thresholds in ISIDE and BSI catalogues within the study region. One can estimate the completeness magnitude threshold before April 15, 2005 at about Mc = 2.5; for more recent time it is about Mc=2.0 or even smaller. The frequency-magnitude histogram of the BSI data looks more stable in time than that of the ISIDE data.

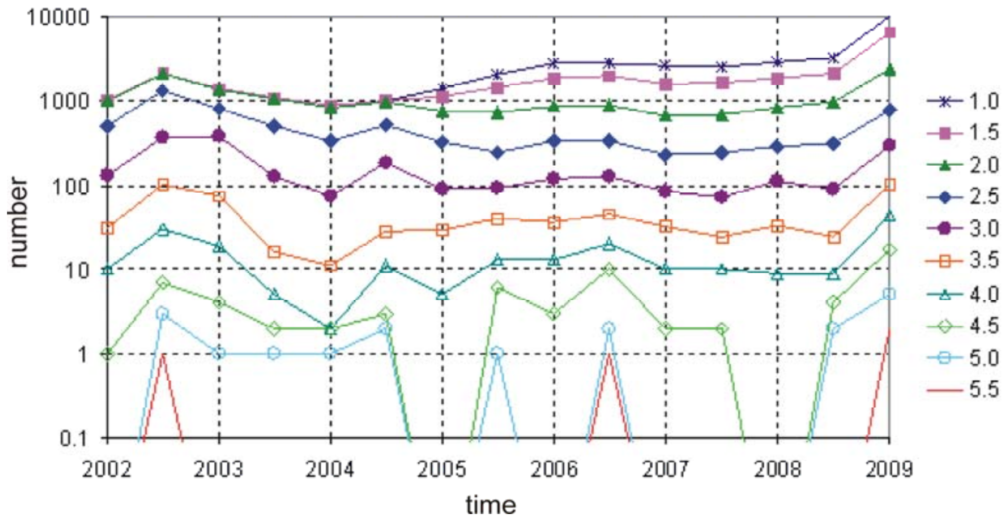


Figure 9. Semi-annual numbers of earthquakes above different magnitude thresholds in merged data sets: ISIDE in 2002 – April 15, 2005, and BSI in April 16, 2005 – June 25, 2009, within CSEP-TRI.

The G-R graphs (Fig. 10) confirm our preliminary conclusions about the completeness magnitude threshold: for ISIDE it is about 2.5 or even higher, and for BSI it is about 2.0. The slope of G-R graphs for the two datasets is different: for ISIDE (*MD* magnitude) it is steeper than for BSI (*ML* magnitude). For ISIDE data a change of the slope around magnitude 4.5 is visible, which may be explained by the switch from *MD* magnitude to *ML*. For BSI data the slope slightly increases for magnitudes ≥4.8.

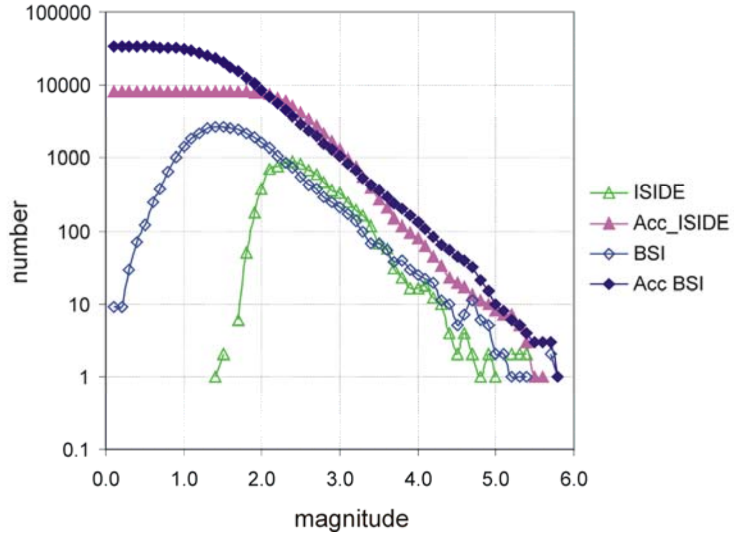


Figure 10. Frequency-magnitude histograms (non-cumulative and cumulative) of earthquakes in ISIDE (triangles) and BSI (diamonds) catalogues, within CSEP-TRI.

Figure 11 combines the semi-annual counts from Figures 4 and 9. Along with natural variation of seismic activity one can observe an evident 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 catalogues. To investigate this phenomenon we compare in the next section the magnitudes of the events common to the two catalogues (i.e., so-called equivalent events) and then, we compare all INGV/CSEP datasets with the NEIC catalogue.

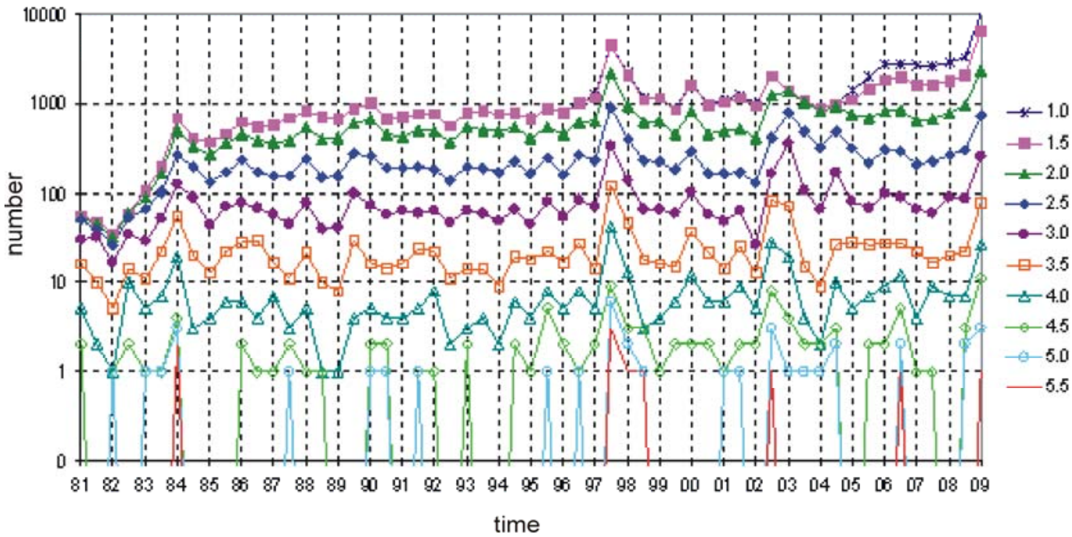


Figure 11. Semi-annual number of earthquakes above different magnitude thresholds in merged data sets: CSI, 1981 – 2002, ISIDE, 2003 – April 15, 2005, and BSI, April 16, 2005 – June 25, 2009, within CSEP-TRI.

3. Magnitudes comparative analysis

3.1. CSI1.1 versus ISIDE data, 2002

About 85% of the events reported in the CSI1.1 catalogue in 2002 have an equivalent in ISIDE database, and vice versa. In our definition the equivalent events are those differing by less than 1 minute in origin time, 0.5^0 in latitude, and 0.7^0 in longitude. No limitations on magnitudes and depth are set. The magnitude of the majority of equivalent events in ISIDE is *MD*, and only for 2% events *ML* is given. In CSI1.1 all magnitudes are *ML*, although estimated in different ways, as described in section 2.1. Figure 12 shows a systematic shift, ΔM, between ISIDE and CSI magnitudes. The average ΔM is 0.49 with standard deviation 0.28 and it comes exclusively from ISIDE *MD* magnitude. For 52 out of the 55 earthquakes whose size is defined by *ML,* all moderate or large events, the difference with CSI1.1 *ML* magnitude equals zero. For $M_{ISIDE} \geq 3.0$ ΔM is 0.35 with standard deviation 0.34.

The distribution of ΔM values and the relation between ΔM and M_{ISIDE} are shown in Figures 13 and 14, respectively. The decrease of ΔM for large magnitudes is clearly visible from Figure 14.

Figure 15 shows the discrepancy between the two catalogues by means of the G-R frequency-magnitude plots.

Thus, we can conclude that, in 2002, CSI1.1 and ISIDE catalogues have evident discrepancies in magnitudes, which concern first of all earthquakes with magnitude M ≤ 3.5.

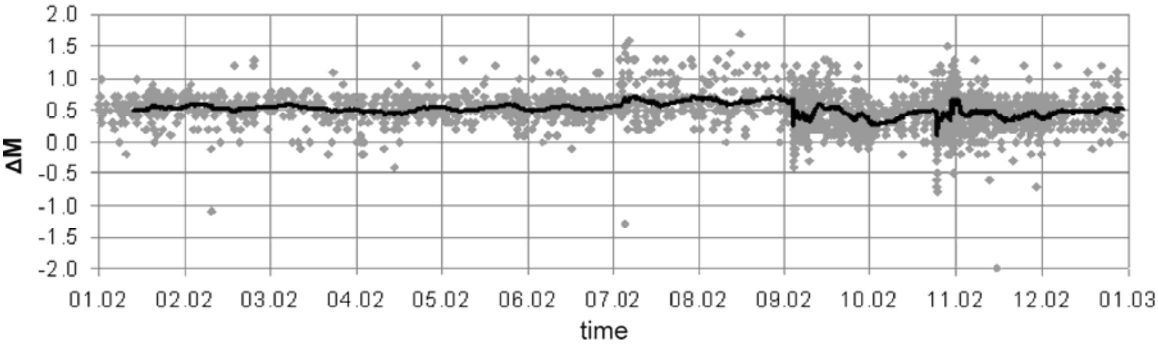


Figure 12. $\Delta M = M_{ISIDE} - M_{CSI}$ versus origin time plot for all earthquakes equivalent in CSI1.1 and ISIDE catalogues in 2002, within CSEP-TRI.

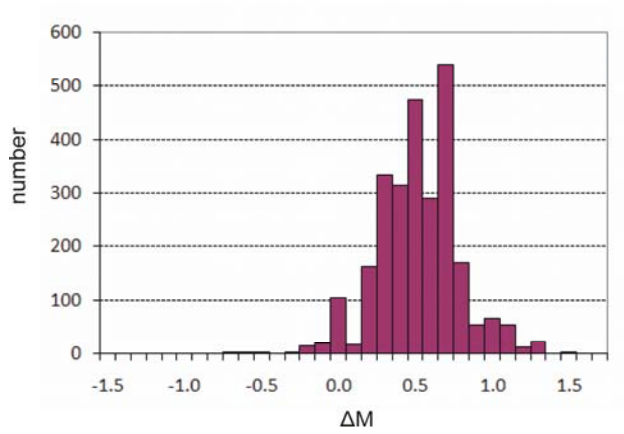


Figure 13. Frequency distribution of $\Delta M=M_{ISIDE}-M_{CSI}$ for equivalent earthquakes in CSI and ISIDE catalogues in 2002, within CSEP-TRI.

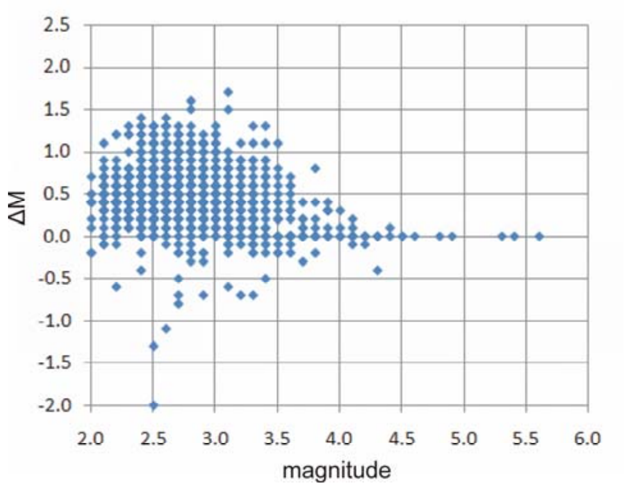


Figure 14. $\Delta M=M_{ISIDE}-M_{CSI}$ versus M_{ISIDE} plot for earthquakes equivalent in CSI and ISIDE catalogues in 2002, within CSEP-TRI.

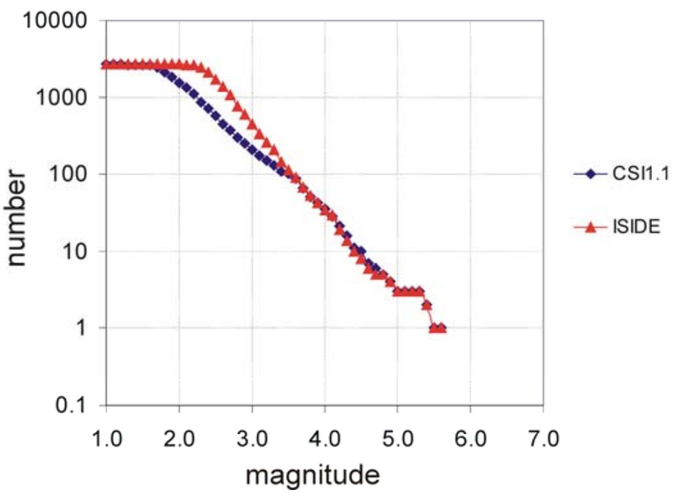


Figure 15. Frequency-magnitude cumulative histograms for equivalent earthquakes from CSI1.1 (diamonds) and ISIDE (triangles) catalogues in 2002, CSEP-TRI.

3.2. CSI1.1 versus NEIC data, 1986-2002

Next we compare CSI1.1 and NEIC catalogues on the territory of CSEP-TRI. The definition of equivalent events is the same used for the comparison of CSI1.1 and ISIDE. To perform the comparison we consider two NEIC magnitudes: *Mmax and M3*. *Mmax* is the maximum of all magnitudes attributed to the earthquake; *M3* is the authority magnitude given in the third magnitude position of each record of the NEIC catalogue, which is mainly *ML* in the Italian area (*Peresan & Rotwain, 1998*). We consider only earthquakes with $M_{NEIC}\geq 3.0$. Figures 16, 17, 18 are similar to Figures 12, 14, 15 and in Figures 16-18 a systematic magnitude shift between CSI1.1 and NEIC catalogues is clearly visible. The average ΔM for $M_{NEIC}=Mmax$ is 0.60, for $M_{NEIC}=M3$ it is 0.51, with standard deviation 0.4 in both cases. Figure 18 does not suggest evident correlation between ΔM and earthquake size.

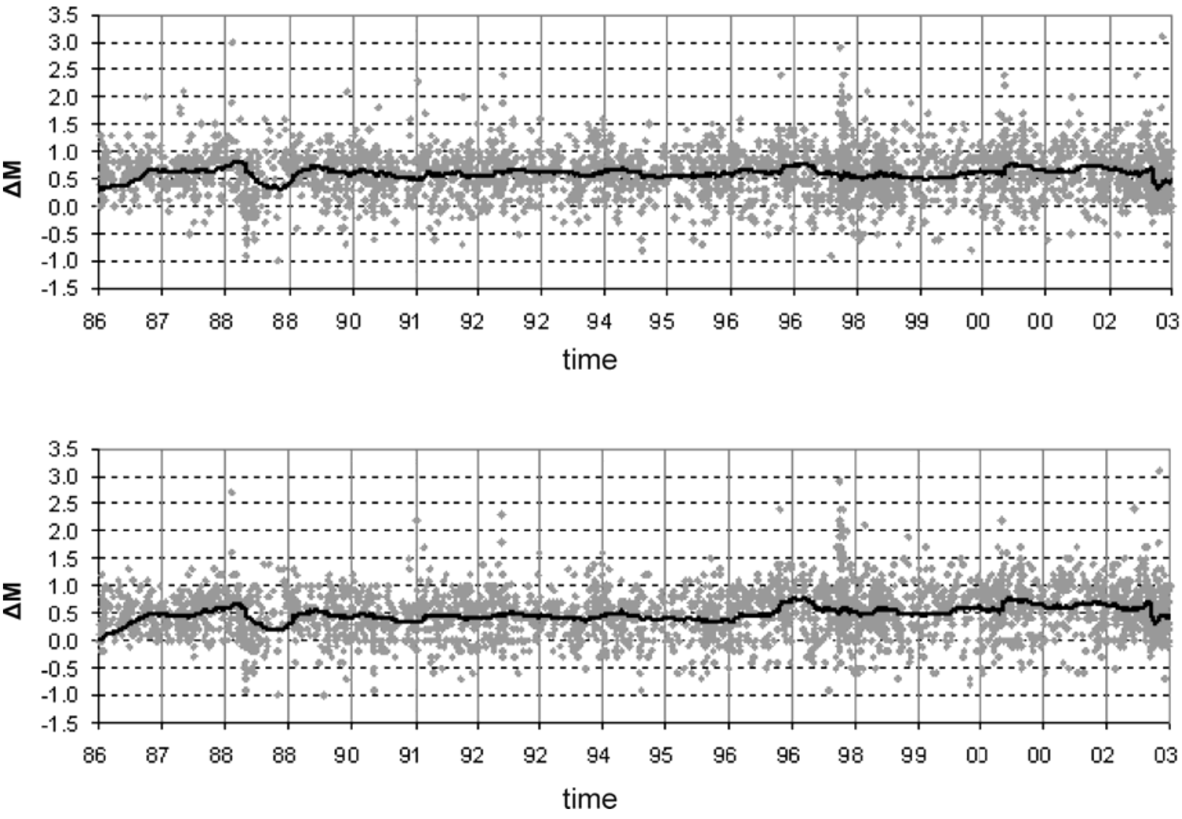


Figure 16. $\Delta M=M_{NEIC}-M_{CSI}$ versus origin time plots for earthquakes equivalent in NEIC and CSI1.1 catalogues, $M_{NEIC}\geq 3.0$, $M_{CSI}\geq 1.0$; top: $M_{NEIC}=Mmax$, bottom: $M_{NEIC}=M3$; for CSEP-TRI.

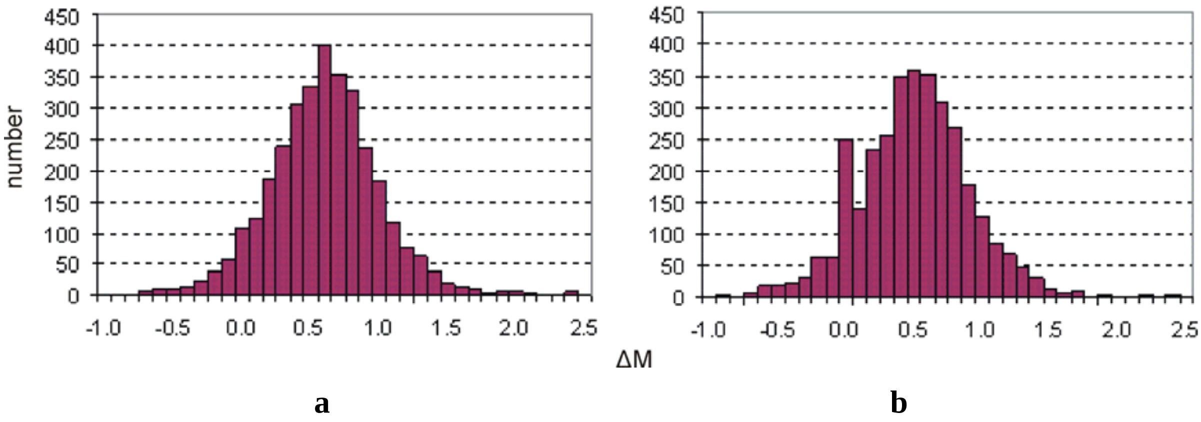


Figure 17. Frequency distribution of $\Delta M = M_{NEIC} - M_{CSI}$ for earthquakes equivalent in NEIC and CSI1.1 in 1986-2002: (a) $M_{NEIC} = Mmax$, (b) $M_{NEIC} = M3$; for CSEP-TRI.

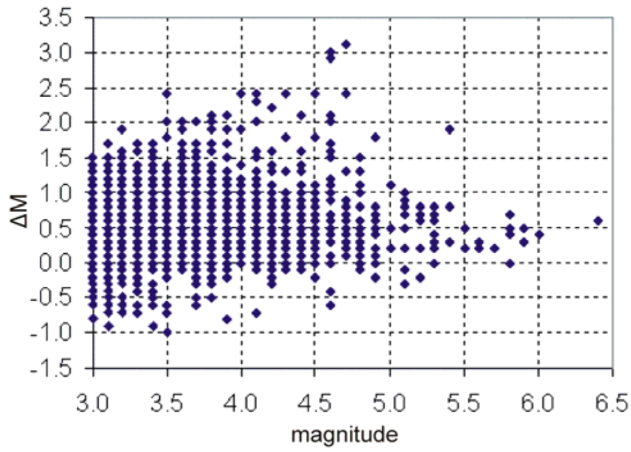


Figure 18. $\Delta M = M_{NEIC} - M_{CSI}$ versus $M_{NEIC} = Mmax$ plot for earthquakes equivalent in NEIC and CSI1.1 in 1986-2002, for CSEP-TRI.

Figures 19 and 20 show frequency-magnitude histograms for CSI1.1 and NEIC catalogues in 1986-2002. For a better comparison, in Figure 20 the G-R plot for magnitude *ML* from CSI1.1 is shifted to a new position by 0.5 (curve *ML*+0.5) which nearly coincides with the *Mmax* plot form NEIC.

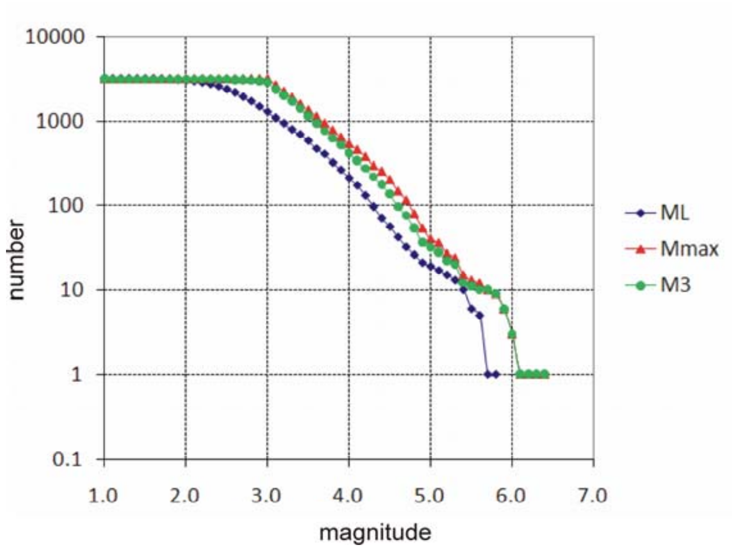


Figure 19. Frequency-magnitude cumulative histograms for earthquakes from CSI1.1 (*ML*) and NEIC (*Mmax* and *M3*) catalogues in 1986-2002, CSEP-TRI.

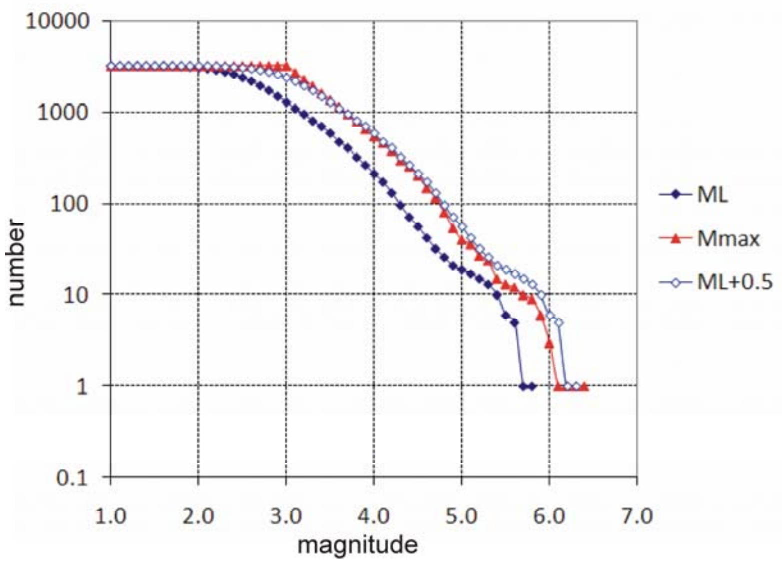


Figure 20. Frequency-magnitude cumulative histograms of earthquakes from CSI1.1 (*ML*) and NEIC (*Mmax*) catalogues in 1986-2002, CSEP-TRI. The curve with *ML*+0.5 shift is shown for comparison.

Thus we can conclude that catalogues CSI1.1 and NEIC have a systematic shift in magnitude of about 0.5 in the time interval from 1986 to 2002.

3.3. ISIDE and BSI bulletins versus NEIC data, 2002-2008

We compare the magnitudes reported in NEIC and Italian Seismic Bulletins, ISIDE and BSI, for earthquakes which occurred on CSEP-TRI territory in 2002-2008, considering only events with

M_{NEIC}≥3.0. The definition of equivalent events is the same as in the above paragraphs. One can see in Figures 21, 22, 23 a certain difference between NEIC and INGV magnitudes, when M_{NEIC}=*Mmax* is considered. The equivalent earthquakes in NEIC and INGV bulletins that have equal magnitude are about 44% in ISIDE (2002 – April 15, 2005) and this number is 32% in BSI (April 16, 2005 – 2008); the average ΔM in the first period is 0.20 (with standard deviation 0.26), while for the second period the average is ΔM = 0.27 (with standard deviation 0.34). For both ISIDE and BSI there is no evident correlation between ΔM and magnitude, except for a minor decrease of ΔM for 3.0-3.5 magnitude events in ISIDE (Fig. 23a). The results of the comparison, when another NEIC magnitude is used, namely M_{NEIC}=*M3*, are very close to those presented here.

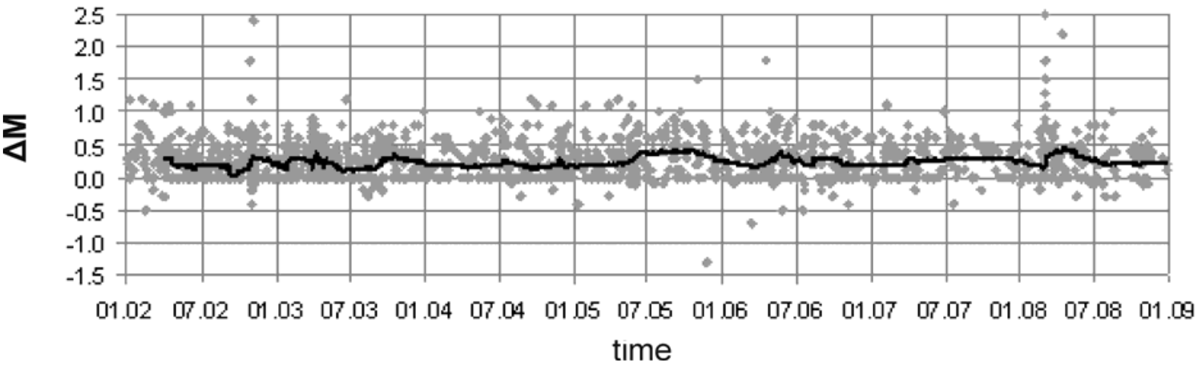
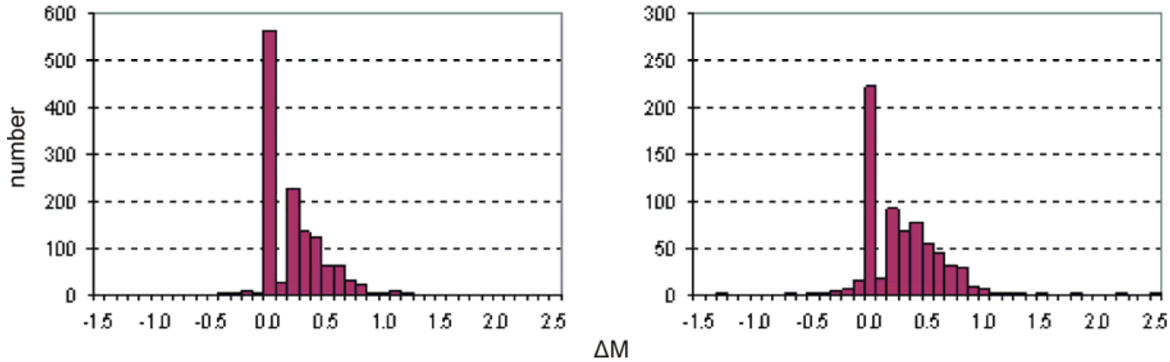
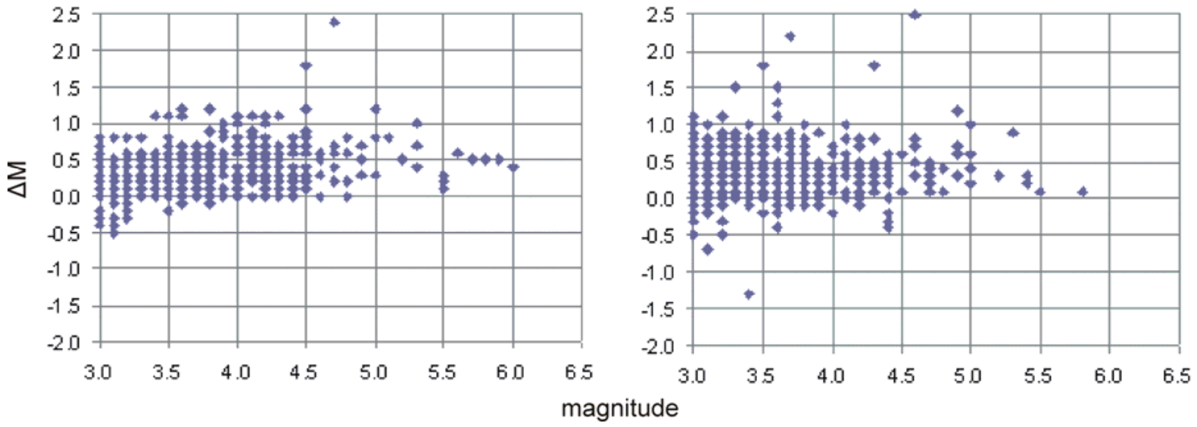


Figure 21. ΔM=M_{NEIC}–M_{INGV} versus origin time plot for earthquakes equivalent in NEIC and INGV datasets, M_{NEIC} ≥3.0, M_{INGV} ≥1.0: M_{NEIC}=*Mmax*; M_{INGV}=M_{ISIDE} in January 1, 2002 – April 15, 2005; M_{INGV}=M_{BSI} in April 16, 2005 – December 31, 2008; CSEP-TRI.



a **b**

Figure 22. Frequency distribution of ΔM= M_{NEIC} –M_{INGV} for earthquakes equivalent in NEIC and INGV datasets, M_{NEIC} ≥3.0, M_{INGV} ≥1.0; M_{NEIC} =*Mmax*; (a) M_{INGV}=M_{ISIDE} in January 1, 2002 – April 15, 2005; (b) M_{INGV}=M_{BSI}, in April 16, 2005 – December 31, 2008; CSEP-TRI.



a **b**

Figure 23. ΔM= $M_{NEIC} - M_{INGV}$ versus M_{NEIC} (*Mmax*) plot for earthquakes equivalent in NEIC and INGV datasets, $M_{NEIC} \geq 3.0$, $M_{INGV} \geq 1.0$: (a) $M_{INGV} = M_{ISIDE}$ in 2002 – April 15, 2005; (b) M_{INGV}=M_{BSI}, in April 16, 2005 –2008; CSEP-TRI.

Figure 24 illustrates the discrepancy between the two catalogues by means of the G-R frequency-magnitude plots.

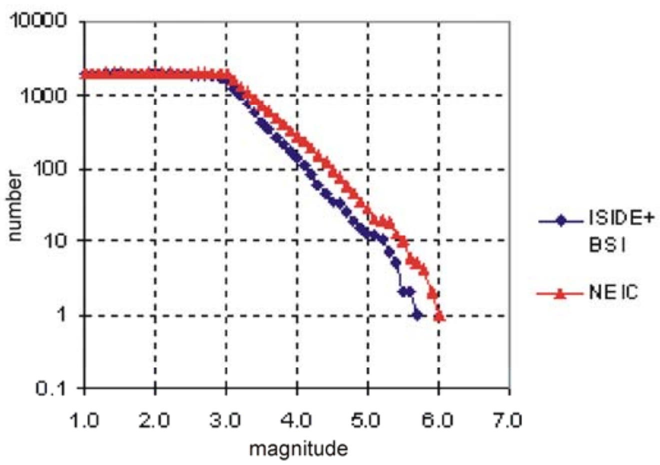


Figure 24. Frequency-magnitude cumulative histograms for equivalent earthquakes from ISIDE+BSI (diamonds) and NEIC (triangles) catalogues, within CSEP-TRI.

Thus we can conclude that, relative to data reported in NEIC, the ISIDE and BSI catalogues exhibit evident discrepancy in magnitudes, particularly for moderate and large earthquakes.

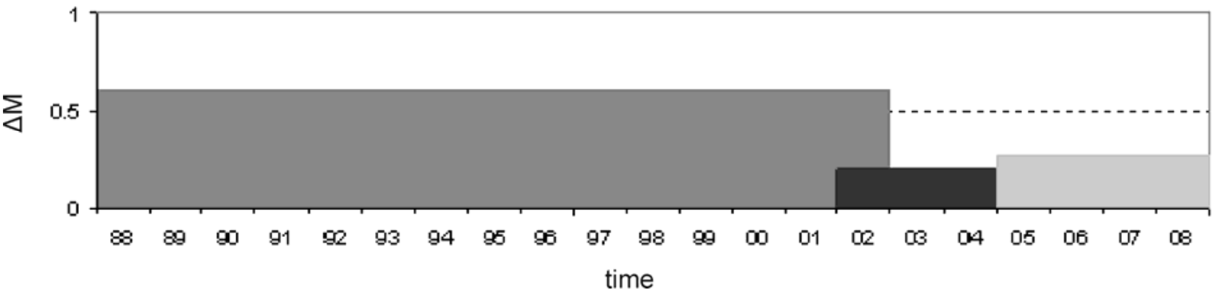


Figure 25. Schematic representation of the average difference between INGV/CSEP and NEIC magnitudes $\Delta M = M_{NEIC} - M_{INGV}$, versus origin time. Notations: $M_{NEIC} = Mmax \geq 3.0$; 1981-2002: $M_{INGV} = M_{CSI}$ (dark grey); 2002 – April 15, 2005: $M_{INGV} = M_{ISIDE}$ (black); April 16, 2005 – December 31, 2008: $M_{INGV} = M_{BSI}$ (light grey).

Figure 25 illustrates schematically the relation between magnitudes in INGV/CSEP and NEIC catalogues. One can see that the average magnitude shift is not constant in time, but specific for each catalogue of the INVG/CSEP database. Of course, one might argue that the observed magnitude shift and its variation in time may result from inconsistencies in either INGV/CSEP or NEIC catalogues, or even in both of them. However, the comparison between CSI1.1 and ISIDE, that is between two parts of INGV/CSEP catalogues in their overlap (see section 3.1), show relative magnitude shifts similar to those observed in the comparison of CSI1.1 with NEIC. Therefore it is natural to conclude that the magnitudes of the INGV/CSEP database are not calibrated to a common scale (at least in time).

3.4. INGV versus NEIC data, *ML* magnitude, 1981-2008

The results presented in the previous sections are confirmed by the following additional analysis, restricted to local magnitude estimates *ML*. Following *Peresan et al. (2000)*, a comparative analysis of *ML* reported in the NEIC catalogue and in INGV/CSEP data sets has been performed considering the events common to the two catalogues within the CSEP-TRI. Specifically, the variation of yearly averages for $\Delta M = ML_{NEIC} - M_{INGV}$ (Fig. 26), estimated for all the common events with $ML_{NEIC} \geq 3.0$, indicates the presence of a major discontinuity and, therefore, a significant inconsistency of the magnitude determination in INGV/CSEP data over the period 1981 – 2008. The relative local magnitude underestimation evidenced in Fig. 26, as well as its time variations, significantly exceeds statistical uncertainties, with an average variation of about 0.4-0.5 in ΔM passing from CSI1.1 to ISIDE-BSI data set. One might argue that the ΔM shift in 2002 is due to the fact that most of the magnitudes reported in ISIDE bulletin do correspond to duration magnitudes, while CSI1.1 reports mainly local magnitudes. Nevertheless, no similar shift is detected between ISIDE and BSI bulletin, where only local magnitude is provided. This observation substantiates the internal inconsistency of INGV data proposed for CSEP testing in Italy. Despite of the recent magnitudes revision reported by *Castello et al. (2007)* for the CSI1.1 catalogue, the average local magnitude underestimation of about 0.5-0.6 (Figs. 27, 28), identified in the period 1986-2002, appears well comparable with that detected by *Peresan et al. (2000*) in 1986-1998 considering an earlier version of INGV data.

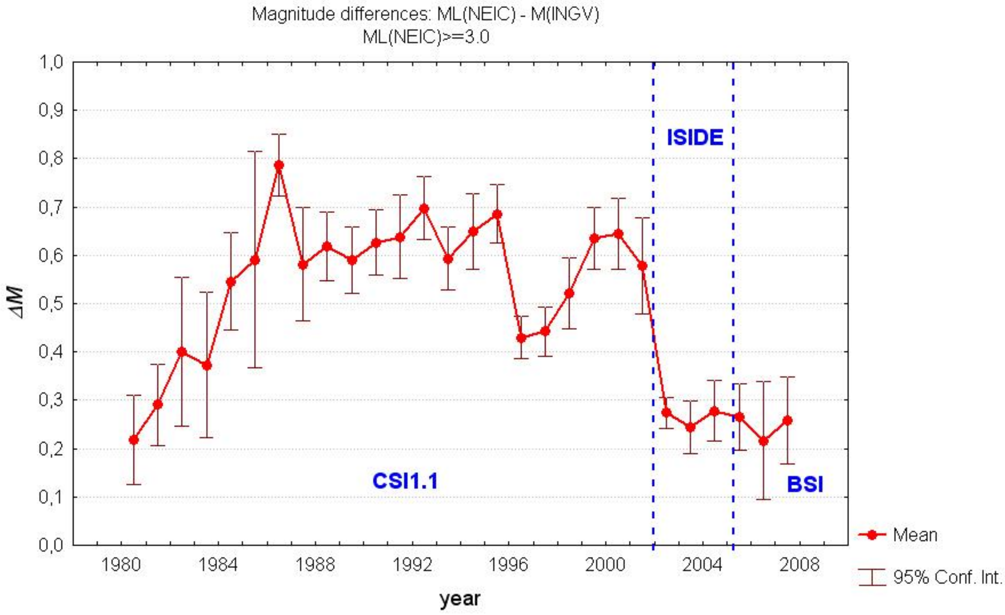


Figure 26. Yearly average of *ΔM* obtained for the NEIC and INGV/CSEP catalogues, considering the common events that occurred within the CSEP-TRI. Error bars correspond to the 95% confidence interval of the mean.

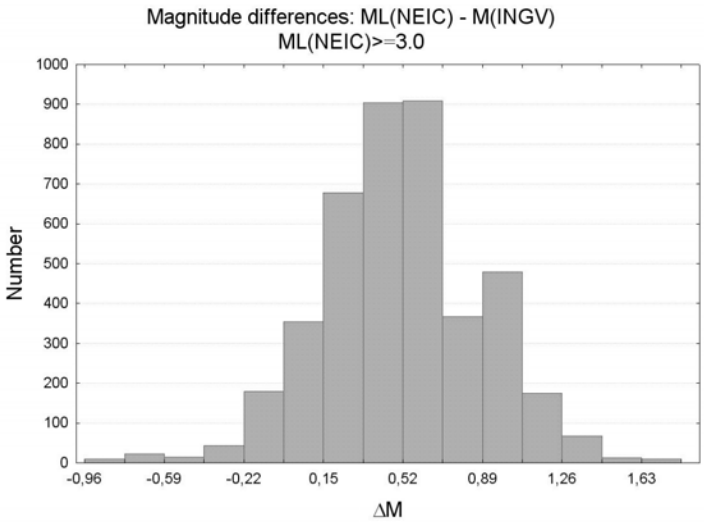


Figure 27. Distribution of magnitude differences *ΔM* obtained for the NEIC and INGV/CSEP catalogues, considering the common events that occurred within the CSEP-TRI in 1986-2002.

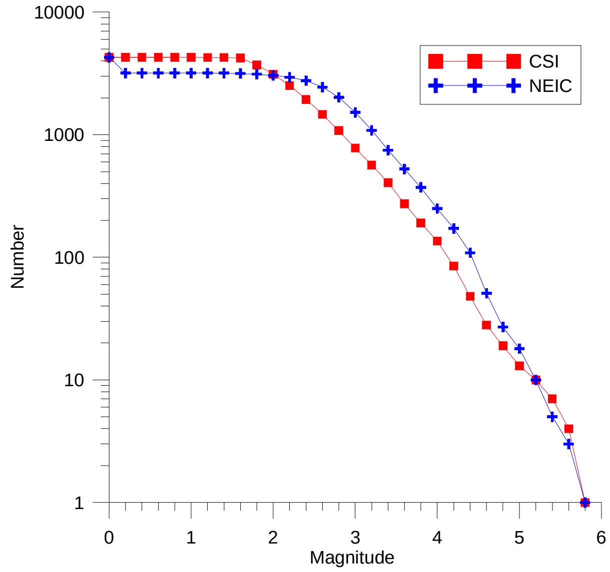


Figure 28. Frequency-magnitude cumulative distribution for all equivalent earthquakes from CSI1.1 and NEIC catalogues, which occurred within CSEP-TRI in 1986-2002.

As described in section 2.1, the size of each earthquake in the CSI1.1 catalogue is defined by a single magnitude value; nevertheless the estimates can be of different type, depending on the considered time window and magnitude range. Specifically, the predominant magnitude types are: 1) *ML* estimated from durations (1983-2002); 2) *ML* from CSTI1.0 Catalogue (1981-1995), and 3) *ML* from MedNet (1996-2002). To better understand the variations evidenced in Fig. 26, the comparative analysis of NEIC and INGV local magnitudes has been performed considering separately the different magnitude types (Fig. 29). Figure 29 clearly evidences that the largest differences ΔML are associated with local magnitudes obtained from duration, with a mean value $\Delta M1$ around 0.6, and eventually with magnitude estimates from MedNet, with $\Delta M3 \approx 0.5$.

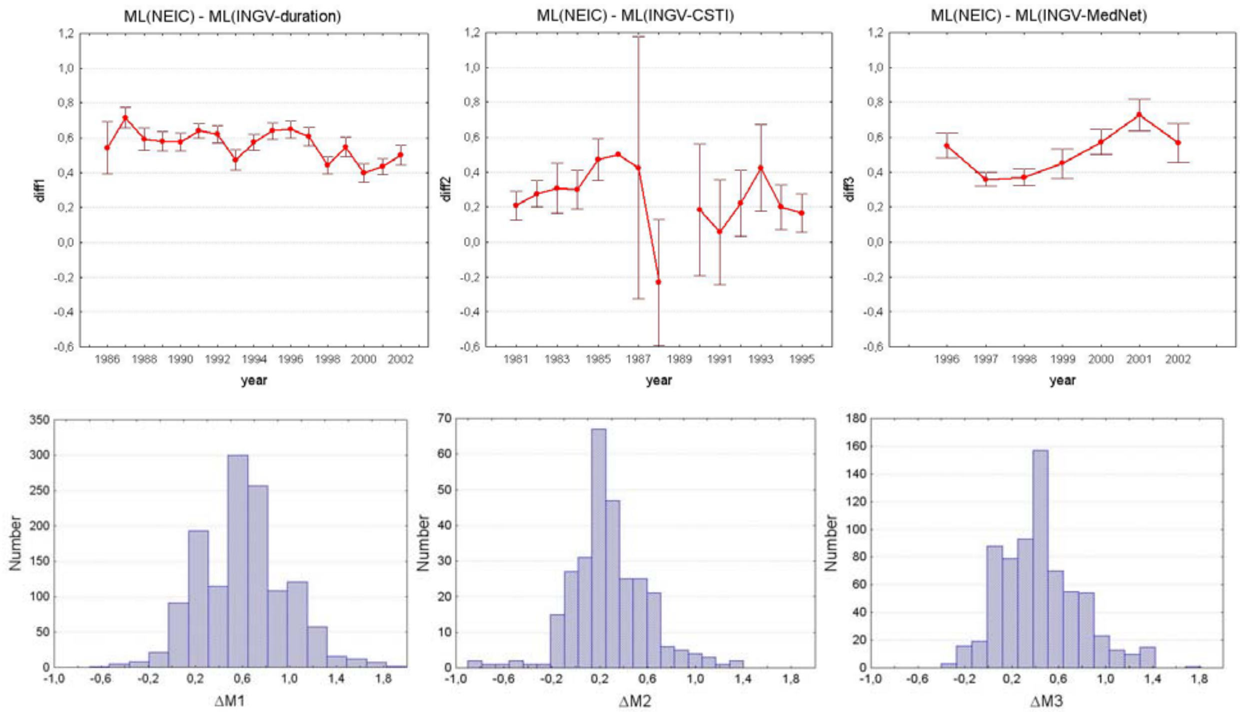


Figure 29. Yearly average and distribution of *ΔML* obtained for the NEIC and CSI1.1 catalogues, considering the common events with $ML_{NEIC} \geq 3.0$ that occurred within the CSEP-TRI in 1981-2002. Different local magnitude estimates from CSI catalogue are analysed separately: 1) *ML* estimated from durations; 2) *ML* from CSTI1.0 catalogue; 3) *ML* from MedNet.

The discrepancies between the *ML* values reported in the INGV/CSEP database with respect to those reported in NEIC global earthquake catalogue appear to be too large and cannot be ignored.

Summarizing, we can conclude that the union of the catalogues CSI1.1, ISIDE and BSI, made by consecutive merging without an appropriate calibration of magnitude scales, cannot be used for any uniform analysis of seismic variability in 1981-2008 due to significant inconsistencies of magnitude determinations both between its different sub-parts and with respect to the independent determinations supplied by NEIC.

4. Spatial comparison of INGV and NEIC data for CSEP-TRI

4.1. Comparison of completeness

The comparison of the INGV/CSEP and NEIC data for the territory of CSEP-TRI is done following the method described in *Kossobokov et. al. (1999),* considering three periods of time: 1986 – 2002, 2002 – April 15, 2005, and April 16, 2005 – 2008. In the first step the NEIC data with *Mmax*≥3.0 are used as the reference test set (NEIC test set) against which the INGV/CSEP catalogues, i.e., CSI1.1, ISIDE and BSI respectively, are tested. Since the depth of the earthquakes in INGV/CSEP catalogues is ≤ 30 km, so only shallow NEIC events with depth 0-50 km are included in the comparison. In the NEIC test set, we identify the earthquakes that have an equivalent among all earthquakes from INGV/CSEP catalogues. The definition of equivalent events is the same as in the previous paragraphs. We coarse grain the territory of CSEP-TRI into one by one degree cells. Within each cell we count the total number of earthquakes from the NEIC test set (N), and the number of earthquakes from the NEIC test set that have an equivalent in the catalogue INGV/CSEP (n). The ratio (n/N) characterises the completeness, in a given cell, of INGV/CSEP catalogue with respect to NEIC test set. The spatial distribution of the n/N ratio (in %) is shown in Figure 30 a,b,c. Three levels of completeness corresponding to the ratio >75% (dark grey), >50% (grey) and >33% (light grey) are shown. In the second step three INGV/CSEP catalogues, magnitude ≥ 3.0, are used as the test set for comparison with the NEIC data. Results are illustrated in Figures 30 d,e,f.

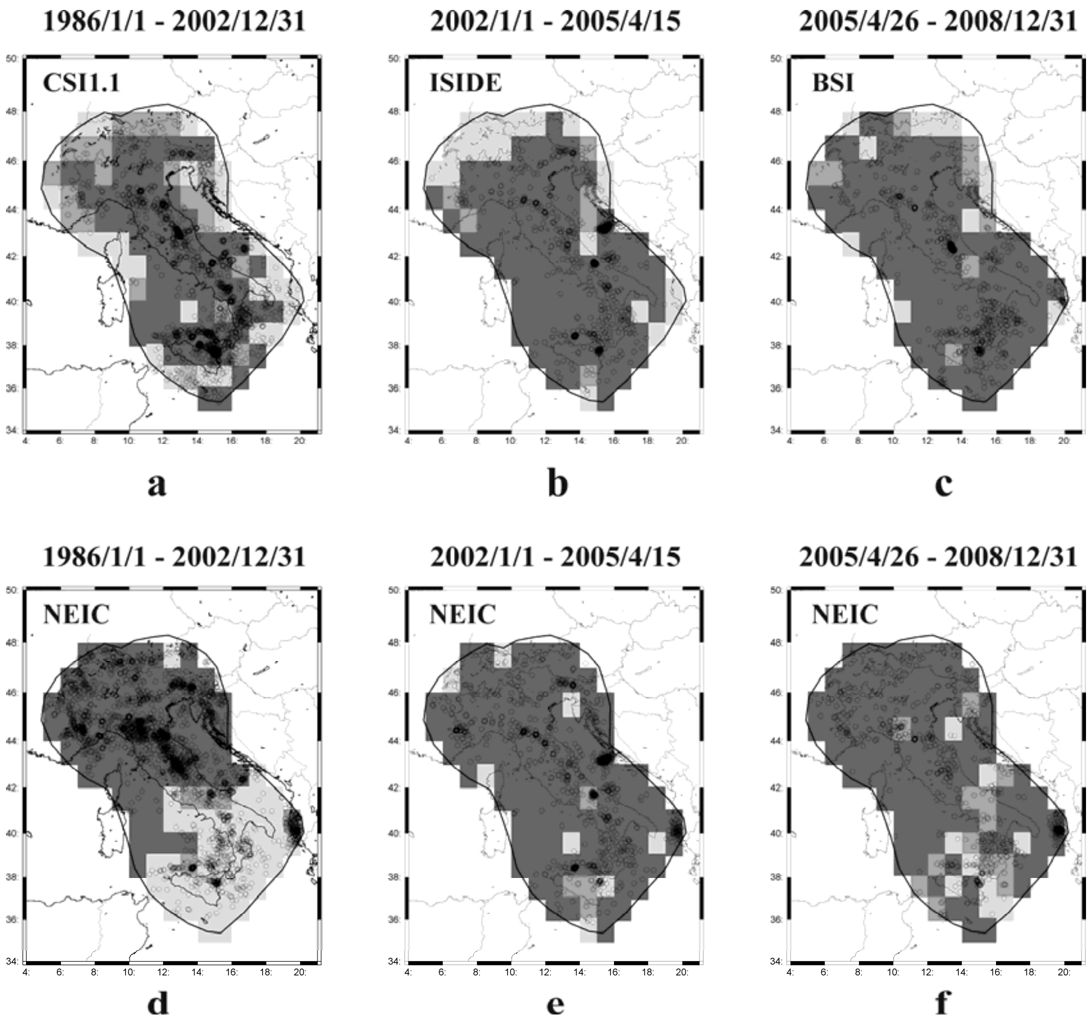
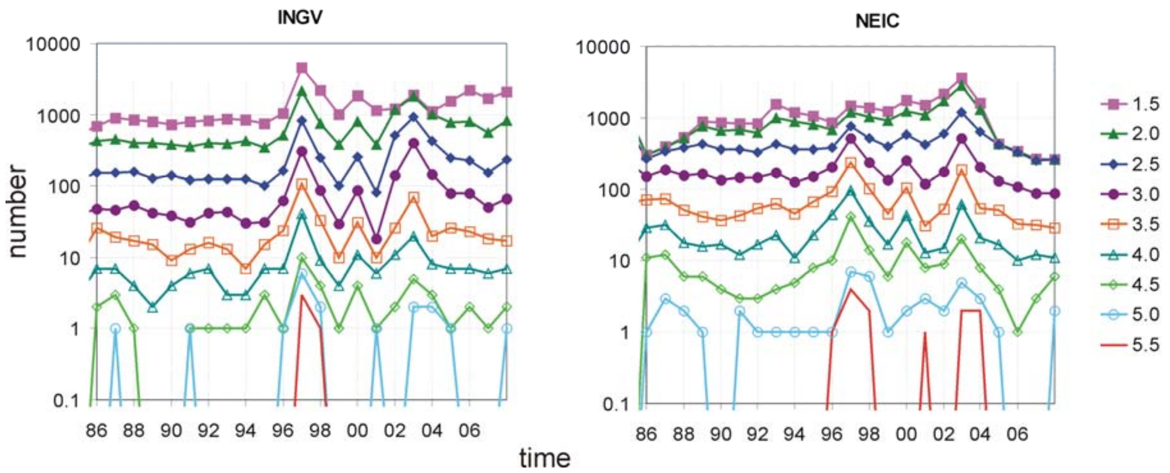


Figure 30. Spatial distribution of n/N ratio (see text for the details) for INGV/CSEP (a,b,c) and NEIC (d,e,f) catalogues in three time intervals. The CSEP-TRI polygon and epicentres of all depth earthquakes from the catalogues under test are shown as well.

Comparing Figures 30a and 30d one can see that in the southern part of CSEP–TRI the CSI1.1 catalogue is more complete than the NEIC one. At the same time NEIC appears more complete than CSI1.1 in the northern, north-western and north-eastern borders of the region. ISIDE and NEIC datasets are comparable for most of the region, except for the northern borders where the dominance of NEIC is evident (Figs. 30b,e). The problem in the north seems to persist in the BSI catalogue, which looks more complete than NEIC in some parts of the southern areas (Figs. 30c,f).

Figures 31 and 32 show the temporal evolution of annual earthquake rates in INGV/CSEP and NEIC datasets in two parts of the CSEP-TRI, north and south of 42^0N, respectively. In the north NEIC catalogue is quite stable in time at least for magnitude $M \geq 2.5$, while INGV/CSEP data reveal certain magnitude heterogeneity before and after 2002. Magnitude shift between the INGV and NEIC is clearly visible from the comparison of the two graphs. In the south NEIC data is unstable due to the evident lack of events with magnitudes $M \leq 3$: the INGV data before 2002 appear more uniform and complete than NEIC. However, the stability of the NEIC magnitude 4.0 curve is remarkable and points to some problem with magnitude values attributed by INGV to large earthquakes in 1986-1995.



a b

Figure 31. Annual numbers of earthquakes above different magnitude thresholds (different marked lines) in the catalogues a) INGV: CSI1.1 in 1986 – 2002, ISIDE in 2003 – April 15, 2005, BSI in April 16, 2005 – 2008; b) NEIC, *Mmax*; in CSEP-TRI, north of 42^0N.

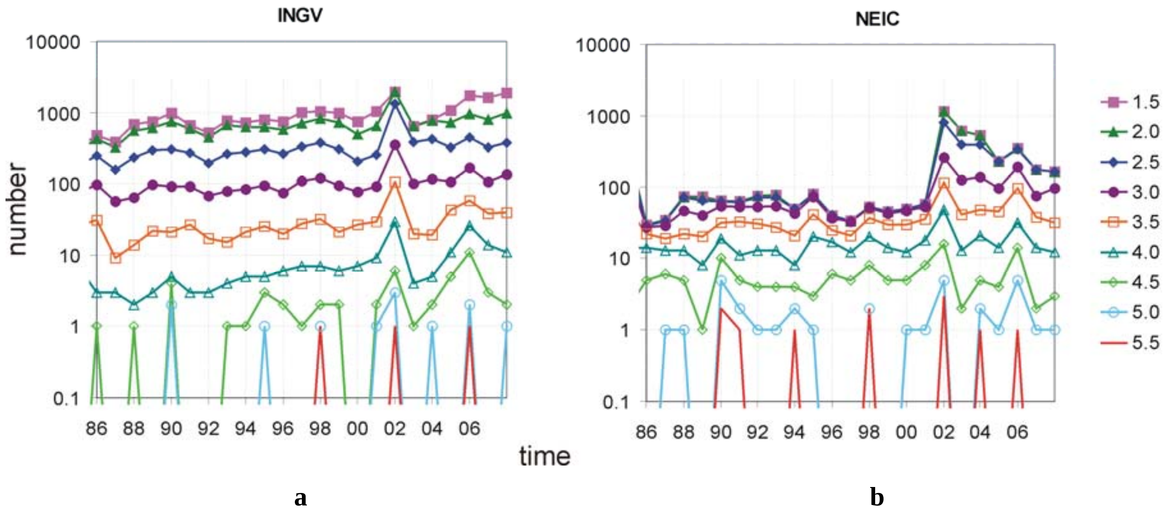


Figure 32. Annual numbers of earthquakes above different magnitude thresholds (different marked lines) in the catalogues a) INGV: CSI1.1 in 1986 – 2002, ISIDE in 2003 – April 15, 2005, BSI in April 16, 2005 – 2008; b) NEIC, *Mmax*; in CSEP-TRI, south of 42^0N.

Thus, the comparison of the spatial completeness of INGV and NEIC data for CSEP-TRI reveals territorial inconsistency between the two datasets: (i) in central Italy the earthquake distributions are comparable during the whole time considered; (ii) in the northern borderlands the NEIC data dominate; (iii) in the south the INGV data, for the period 1986-2001, are evidently superior. The magnitude shifts observed in the INGV/CSEP catalogues for the entire CSEP-TRI seem to have different origin in different territories.

4.2. Comparison of spatial distributions

Each of the six maps in Figure 33 shows the empirical spatial probability density distribution function (i.e. *pddf*) of the earthquake recurrence in 3/4°×3/4° cells centred at the grid-points of a 1/4°×1/4° mesh, ***p***, determined by using specified data source and time interval. All data was cut to the CSEP-TRI outlined in the figure. The top row provides the three *pddf*'s for earthquakes of magnitude M ≥ 3.0, reported in the CSI1.1 data set from January 1, 1986 through 2002, in the ISIDE bulletin from January 1, 2002 to April 15, 2005, and in the BSI bulletin from April 16, 2005 through 2008, respectively. For an easy comparison the *pddf*'s determined for the earthquakes reported in the NEIC data, for the same three intervals of time, are given below. In line with the main conclusion reached in paragraph 3.2, the M_{max} magnitude cutoff is set to 3.5 for NEIC in 1986-2002. The third row of maps displays distribution of the $\log_2(\boldsymbol{p}_{\rm CSI}/\boldsymbol{p}_{\rm NEIC})$, $\log_2(\boldsymbol{p}_{\rm ISIDE}/\boldsymbol{p}_{\rm NEIC})$, and $\log_2(\boldsymbol{p}_{\rm BSI}/\boldsymbol{p}_{\rm NEIC})$ and the values around 0 (i.e., comparable values of ***p***) indicate general agreement in the reconstruction of the recurrence density. The last row in Figure 33 provides the density distribution of the three logarithms of the ratio for each of the three intervals of time.

By inspection of the three pairs of *pddf*'s, of their ratios, and of the ratio distribution graphs one can make knowledgeable suggestions on the consistency of CSEP-TRI and NEIC data, their spatial homogeneity and completeness in different time intervals, as well as on the changes in territorial completeness of CSEP-TRI on transition from one INGV data set to the next one. In particular, the extreme polarization of completeness is evident for the period from 1986 to 2002, at which times more than one third of the recurrence ratios or their inverses exceed a factor of 2. Specifically, 29.5% of the ratios, mainly in the north (above 43°N), are less than 0.5, indicating deficiency of the CSI data, while 5.4%(mainly in Sicily, about Etna volcano) are greater than 2, indicating an extremely high rate of seismic events reported in the CSI1.1 data source in comparison with the NEIC data, which is presumably stable in 1986-2002. Note that in 2002-April 15, 2005 more than 93% of the ratios (2.2% below 0.5, and 4.7% above 2) are in reasonable agreement (i.e., $|\log_2(\boldsymbol{p}_{\mathrm{ISIDE}}/\boldsymbol{p}_{\mathrm{NEIC}})| < 1$), which percentage drops down to about 85% (2.5% and 12.3%, respectively) in April 16, 2005-2008.

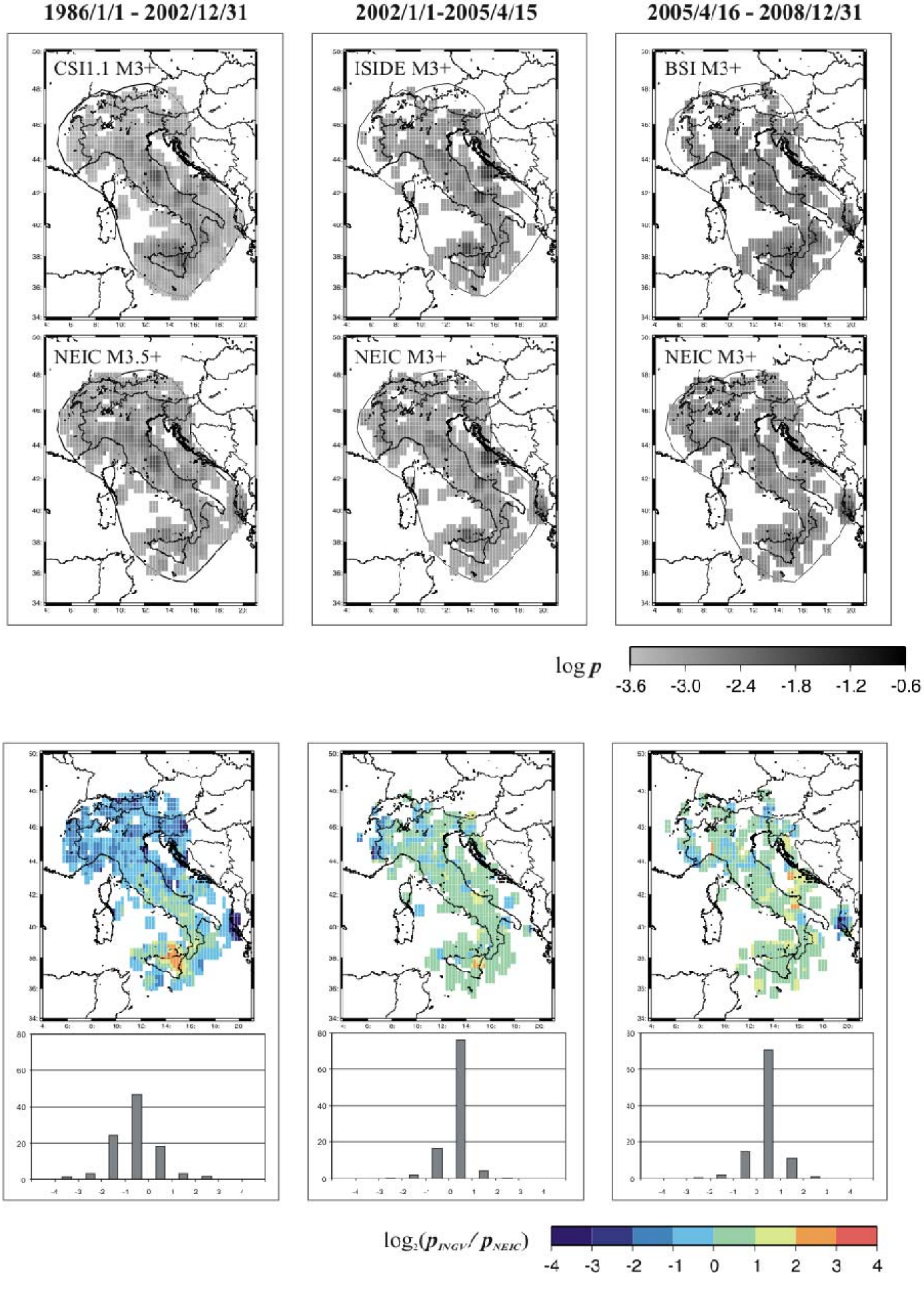


Figure 33. Empirical spatial probability density distribution functions of the recurrence of earthquakes determined from different data sources in the CSEP-TRI (outline). Note: the two top rows display *pddf*'s; the two at the bottom show the $\log_2(\boldsymbol{p}_{\mathrm{CSI}}/\boldsymbol{p}_{\mathrm{NEIC}})$, $\log_2(\boldsymbol{p}_{\mathrm{ISIDE}}/\boldsymbol{p}_{\mathrm{NEIC}})$, and $\log_2(\boldsymbol{p}_{\mathrm{BSI}}/\boldsymbol{p}_{\mathrm{NEIC}})$ and their density distributions in percent.

5. Conclusions

A detailed analysis of the authoritative instrumental data made available in the framework of the Collaboratory for the Study of Earthquake Predictability in the Test Region Italy (CSEP-TRI), namely the earthquake catalogue and seismic bulletins compiled at the Istituto Nazionale di Geofisica e Vulcanologia (INGV), has been carried out in order to assess their homogeneity and completeness.

The study evidenced that the different INGV data sets, which are proposed for CSEP models development and testing, are significantly heterogeneous over space and time, as demonstrated by the comparative analysis performed considering the CSI1.1, ISIDE and BSI data sets, as well as the global NEIC data.

The most relevant problems concern the magnitude estimates reported in INGV/CSEP data sets. Although *ML* is announced as the reference magnitude scale for CSEP models development and testing, the magnitudes reported in INGV/CSEP catalogues are not uniform. In CSI1.1 the *ML* estimates are of three significantly different types, depending on the considered time window and magnitude range; in ISIDE the reported magnitude is mostly *MD*, while in BSI it is mostly *ML*. The inconsistency of magnitude is clearly evidenced by the cross-comparison of the CSI1.1 and ISIDE data during the year 2002, when both of them are available; the average magnitude difference for the equivalent earthquakes reported in the two catalogues is about 0.5. The comparison with global NEIC data confirms the heterogeneity of the INGV/CSEP magnitude estimates over the period 1981 – 2008. Specifically, the CSI1.1 catalogue available for the period 1986-2002, despite of its recent revision *(Castello et al., 2007),* appears affected by a relevant systematic magnitude underestimation with respect to NEIC; the average magnitude difference is around 0.5, which is well comparable to that evidenced so far by *Peresan et al. (2000)* considering an earlier version of INGV data, and *Gasperini et al. (2001)*. The ISIDE and BSI bulletins also display some magnitude discrepancy with respect to NEIC, although differences are smaller. Therefore, the magnitude shift between INGV/CSEP and NEIC data is not uniform, but specific for each part of INVG/CSEP data set.

According to the information provided via the CSEP website, the ISIDE seismic bulletins available prior to April 16, 2005 are reported under revision (*Christophersen et al., 2009*), which eventually makes the current INGV data set discontinuous in time. The most recent part of the data, namely BSI bulletins compiled since April 2005, displays a better agreement with NEIC data and is characterised by comparatively high completeness level, especially in peninsular Italy; nevertheless, due to its very short time span, it still does not allow for any representative description of Italian seismicity, especially at intermediate-term time scale.

The spatial homogeneity of the INGV data completeness, as well as the changes in territorial completeness on transition from one data source to the subsequent one, have been investigated following two approaches, one based on probability density distribution functions (*pddfs*) of earthquake epicentres and the other on the ratio of common events *(Kossobokov et al.,* *1999),* using the NEIC catalogue as reference data set. The analysis evidenced a remarkable territorial inconsistency of the Italian data in the reporting of earthquakes for the period from 1986 to 2002, i.e. certain deficiency of the CSI1.1 in comparison with NEIC data mainly in the north (above 43°N), and relatively high rate of seismic events in the south (particularly Sicily).

Based on the outcomes of this study, we have to conclude that the catalogues provided by the Istituto Nazionale di Geofisica e Vulcanologia for forecast/prediction modellers as the authoritative database for the first testing region within Europe, i.e. CSEP Testing Region Italy (CSEP-TRI), is hardly a unified data base acceptable for the necessary model/algorithm tuning before running any rigorous predictability test. The catalogue problem disclosed in our study appears to be complex, involving not only some systematic magnitude shifts at specific times, but also a number of territorial inconsistencies. An effective solution of the problem very likely requires a uniform, systematic compilation of the catalogue from the original seismograms. As a viable alternative, of a rather limited magnitude range though extended in time for decades, we may recommend to use the USGS/NEIC Global Hypocenters Data Base System (i.e., NEIC catalogue, *GHDB, 1989*) or UCI2001 catalogue (*Peresan et al., 2002*) that was used in July 2003, when setting up the ongoing real-time earthquake prediction experiment in Italy (*Peresan et al., 2005*).

Acknowledgments

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References

Castello, Olivieri.M, and Selvaggi.G, (2007). Local and Duration Magnitude Determination for the Italian Earthquake Catalog, 1981–2002 , 97, 128–139.

Christophersen, A., W. Marzocchi, S. Wiemer, (2009). Summary of analysis of CPTI08 and CSI1.1 catalogues, http://eu.cseptesting.org/TestingRegionItalyCatalogs

Gasperini P., Vannucci G., Orlanducci L. (2001). Rivalutazione della magnitudo per i terremoti italiani nel periodo post 1980. In: "Catalogo strumentale dei terremoti Italiani dal 1981 al 1996". Version 1.0 – 5.3.2001. Cd-rom.

GHDB (Global Hypocenter Data Base). (1989), Global Hypocenters Data Base CD-ROM NEIC/USGS, Denver, CO, 1989 and its updates through July 2009.

Kossobokov, V.G., K. Maeda, S. Uyeda, (1999). Precursory activation of seicmicity in advance of Kobe, 1995 M=7.2 earthquake, *Pure and Appl. Geoph*., **155**, 409-423.

Peresan, A., Rotwain, I.M., (1998). Analysis and definition of magnitude selection criteria for NEIC (PDE) data, oriented to the compilation of a homogenous updated catalogue for CN monitoring in Italy. ICTP, Trieste, Italy, Internal report IC/98/97.

Peresan. A, Panza. G.F, and Costa. G, (2000). CN algorithm and long-lasting changes in reported magnitudes: the case of Italy. Geophys. J. Int. 141, 425– 437.

Peresan, A., Panza, G.F., 2002. UCI2001: The updated catalogue of Italy, ICTP, Trieste, Italy, Internal report, IC/IR/2002/3.

Peresan , A., V. Kossobokov, L. Romashkova, G.F. Panza, (2005). Intermediate-term middle-range earthquake predictions in Italy: a review, *Earth-Science Reviews*, **69**, 97–132.

Rovida A. and the CPTI Working Group, 2008. Parametric Catalogue of Italian Earthquakes, version 2008 (CPTI08), 1900-2006, http://www.cseptesting.org/regions/italy

Woessner, J. and S. Wiemer (2005). Assessing the quality of earthquake catalogues: Estimating the magnitude of completeness and its uncertainty, *BSSA*, **95(2)**: 684-698.