RELATIONS BETWEEN MP AND ML MAGNITUDE SCALES

M. Popova

National Institute of Geophysics, Geodesy and Geography, BAS, Akad G.Bonchev street, bl.3, Sofia, Bulgaria

Abstract. The work focuses on comparison of the magnitude estimations for near earthquakes determined by the Bulgarian Seismic Center (SOF) with the assessments of the national centers in the neighboring Balkan countries (Romania - BUC, Serbia - BEO, Macedonia - SKO, Greece - THE and NOA and Turkey - KAN) and the European Mediterranean Seismic Center (EMSC). 372 earthquakes located in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E, occurred in 2007 - 2011, with ML magnitudes ranging from 3.0 up to 5.4 (the lower magnitude threshold M = 3.0 is determined by SOF) were used in the study.

Key words: earthquake, magnitude, magnitude estimates, seismic centers

Introduction

The size of the magnitude is a conditional, scalar, dimensionless indicator of seismic energy released in the seismic focus. Since the first work of Richter (1935) when the local magnitude scale, ML, (commonly called Richter magnitude) was initially defined the earthquake magnitude became the most common measure of the size of an earthquake. This magnitude is known in seismology as local magnitude ML or Richter's magnitude.

The introduction of magnitude makes it possible to compare the size of earthquakes in an instrumental way across the world. Magnitude is used to scale up a number of physical characteristics of earthquakes: emitted seismic energy (eg Gutenberg, Richter, 1936. Gutenberg, Richter, 1956); geometric characteristics of the seismic outbreak (eg Riznichenko 1976, Bonilla et al., 1984; Ambraseys, 1988; Wells, Coppersmith, 1994); shifting of the fault (e.g., Bonilla et al., 1984); (Eg, Ambraseys et al., 1996; Ambraseys et al., 2005, et al., 1996), and attenuation of seismic effects (macroseismic intensity, maximum acceleration, velocity and displacement, etc.); size of the aftershock region (e.g., Utsu, Seki, 1954, Konstantinou et al, 2005).

Magnitude scales are used for systemic classification of earthquakes. The classification is relative: the magnitude of an earthquake is determined by comparison and in relation to the normative, reference earthquake. The comparison is absolute in the sense of the definitional formalization, and the zero of the scale depends on the definition of the reference earthquake. Richter sets the foundations of the magnitude scale with his publications dating back to 1935. The scale is based on the following equation:

$$M_L = LogA(D)\text{-}LogA_0(D), \text{ where } M_L = 0\ A(100) = 0.001 \text{ mm}) \qquad (1)$$

The magnitude is defined as the decimal logarithm of the maximum amplitude $logA_0$ (A_0 measured in mm) from a seismogram of the Wood-Anderson torrent seismograph at an epicentre distance of 100 km. The amplitude A(D) measured at distances D is reduced to a standard distance of 100 km using an empirical calibration function $logA_0$ (D) (tabulated for 25<D<600 km, logA0(100)= -3).

At present different magnitude scales are applied in seizmological practice. Most of these scales are mainly based on empirical dependencies containing several constants (or empirically derived functions). These constants are determined in such a way that the magnitudes on the new scale are in agreement (at least in a certain magnitude interval) with an already existing scale. The introduction of many magnitude scales exacerbates the problem of assessing the magnitude of earthquakes. Unfortunately, attempts to introduce a standard magnitude scale into the world have so far failed.

The target of the present work is to compare the M_L magnitude estimates applied in the routine practice of NOTSSI (the Mp magnitude, defined in Christoskov et al., 2012) and local magnitude M_L (defined by Richter) which has been used in many of the Balkan Centers and the European Seismological Center (EMSC / CSEM). The task was sought by comparing the magnitude estimates for 372 near earthquakes (distant from the territory of the country at distances up to 150 km) determined by the Bulgarian Seismic Center (SOF) with the local magnitude (M_L) estimates of the national centers in the neighboring Balkan countries (Romania - BUC, Greece - THE and NOA, Turkey - KAN, FYROM - SKO and Serbia - BEO) and tne European Mediterranean Seismic Center (EMSC).

Input data and method applied

To perform this study it was necessary to create an earthquake catalog with information on all earthquakes, for which magnitudes expressed in the M_L scale estimated by several agencies, were available, and which occurred during the last few decades.

The sample of data used in the study includes: 372 earthquakes located in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E with a ML (marked here M_{sof}) in the interval $3.0 \leq M_L \leq 5.4$ (the lower magnitude threshold M = 3.0 is determined by the NOTSSI); 315 earthquakes determined by the EMSC (marked here M_{emsc}); 88 earthquakes determined by BUC, Romania; 299 earthquakes defined by THE, Greece; 105 earthquakes determined by KAN, Turkey; 115 earthquakes determined by SKO, FYROM; 115 earthquakes set by BEO, Serbia; and 189 earthquakes identified by NOA, Greece.

In the study, a regression analysis was used to minimize mean square deviation using the least squares method (LSQ), which assumes that the independent variable is accurately defined without error.

The study was performed in two stages:

First Stage - It is assumed that the EMSC's magnitude estimates are the most credible because they are based on a large sample of seismological data from the same type of seismometers. To verify this assumption we have plotted M_L given by EMSC versus M_L reported by national centers (SOF, BUC, THE, KAN, SKO, BEO and NOA).

Second Stage - the SOF magnitude estimates are compared with M_L reported by the other national centers (BUC, THE, KAN, SKO, BEO and NOA).

Results

First stage

The results obtained in the first stage of the present study are presented in Figure 1-7. The diagrams illustrate the consistency of M_{emsc} with M_L estimates reported by the national centers.

Figure 1 shows the relation between M_L magnitudes given by EMSC and SOF. 315 events occurred in and around Bulgaria were used. The diagram of Figure1 shows the variation of M_L EMSC versus M_L SOF (least-squares'fit). The relation is:

$$M_{emsc} = 0.98\ M_{sof} + 0.02 \pm 0.33. \quad (2)$$

M_{emsc} / M_{sof} relation is linear for the considered range of magnitudes ($3.0 \leq M_L \leq 4.6$). The relation (2) indicates that the M_L magnitudes given by EMSC and SOF are very close (M EMSC = 0.98 M SOF + 0.02) although the uncertainties are rather high ($\sigma = 0.33$). The data dispersion decreases for magnitudes above 3.5, reaching a value less than 0.3, which is the accuracy of the magnitude determinations.

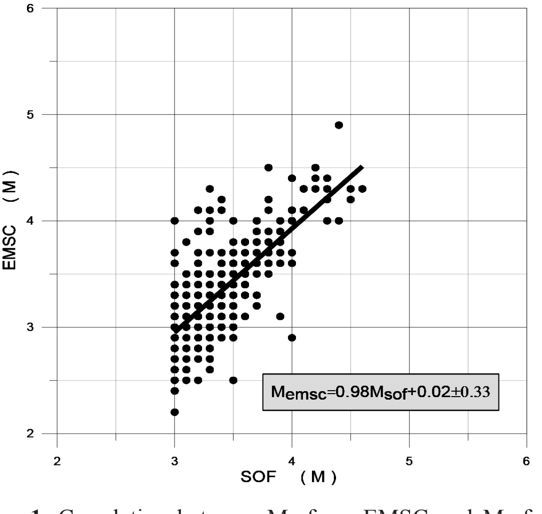

Figure 1. Correlation between M_L from EMSC and M_L from SOF for 315 shallow earthquakes. The straight line is the best fit.

Figure 2 shows the relation between M_L magnitudes given by EMSC and KAN (Turkey). 105 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure2 shows the variation of M_L EMSC versus M_L KAN. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{EMSC} = 0.94\, M_{KAN} + 0.22 \pm 0.18. \tag{3}$$

M_{emsc} / M_{kan} relation is linear for the considered range of magnitudes ($2.6 \leq M_L \leq 4.6$).

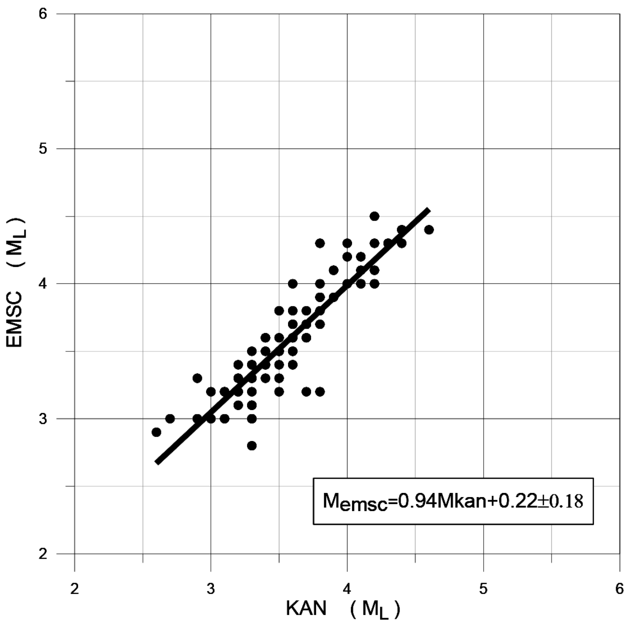

Figure 2. Correlation between ML from EMSC and ML from KAN (Turkey) for 105 shallow earthquakes. The straight line is the best fit.

The relation (3) indicates that the M_L magnitudes given by EMSC and KAN are almost equivalent ($M_{EMSC} = 0.94\, M_{KAN} + 0.22$). Overall, M_L KAN are very slightly higher than the EMSC estimates. The slight bias between M_L EMSC and M_L KAN is observed ($\sigma = 0.18$).

Figure 3 shows the relation between M_L magnitudes given by EMSC and BUC (Romania) 88 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure 3 shows the variation of M_L EMSC versus M_L BUC (least-squares fit). The relation is:

$$M_{EMSC} = 0.68\ M_{BUC} + 1.09 \pm 0.26. \qquad (4)$$

M_{emsc} / M_{kan} relation is linear of the considered range of magnitudes ($2.3 \leq M_L \leq 4.8$).

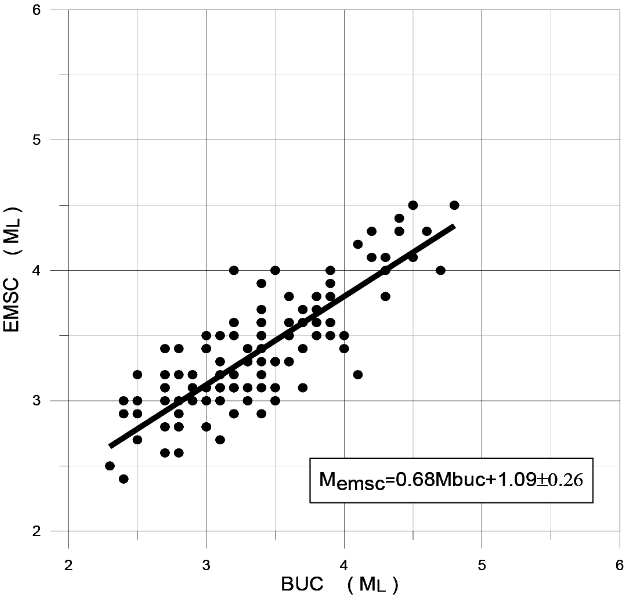

Figure 3. Correlation between ML from EMSC and ML from BUC (Romania) for 88 shallow earthquakes. The straight line is the best fit.

The relation (4) indicates that the M_L magnitudes given by EMSC and BUC canot be considered as equivalent ($M_{EMSC} = 0.68\ M_{BUC} + 1.09$) and the uncertainties are rather high ($\sigma = 0.26$).

Figure 4 shows the relation between M_L magnitudes given by EMSC and THE (Greece). 299 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure4 shows the variation of M_L EMSC versus M_L THE. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{EMSC} = 0.83\ M_{THE} + 0.53 \pm 0.2. \qquad (5)$$

M_{emsc} / M_{the} relation is linear of the considered range of magnitudes ($2.5 \leq M_L \leq 5.5$). The relation (5) indicates that the M_L magnitudes given by EMSC and THE are close ($M_{EMSC} = 0.83$ M the + 0.53) although the uncertainties are high ($\sigma = 0.20$). Overall, THE's estimates are slightly lower than the EMSC estimates.

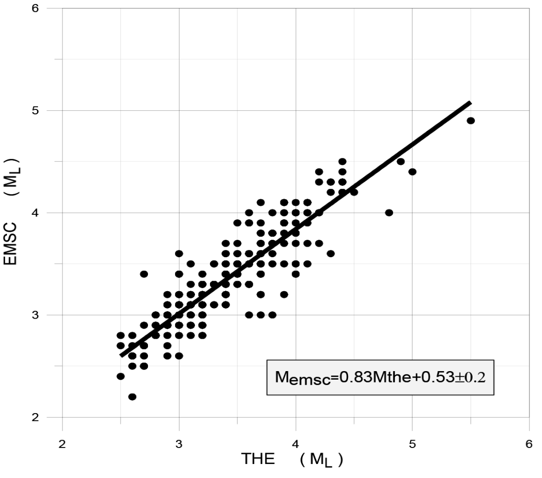

Figure 4. Correlation between ML from EMSC and ML from THE (Greece) for 299 shallow earthquakes. The straight line is the best fit.

Figure 5 shows the relation between M_L magnitudes given by EMSC and SKO (FYROM). 115 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure5 shows the variation of M_L EMSC versus M_L SKO. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{EMSC} = 0.78\ M_{SKO} + 0.832 \pm 0.22. \qquad (6)$$

M_{emsc} / M_{sko} relation is linear of the considered range of magnitudes ($2.0 \leq M_L \leq 4.8$).

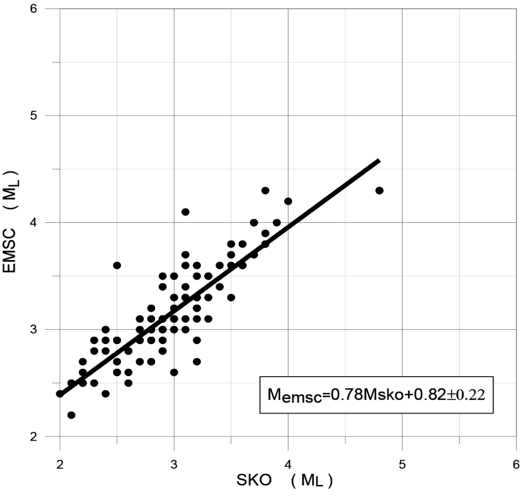

Figure 5. Correlation between ML from EMSC and ML from SKO (FYROM) for 115 shallow earthquakes. The straight line is the best fit.

The relation (6) indicates that the M_L magnitudes given by EMSC and SKO cannot be considered as equivalent ($M_{EMSC} = 0.78\ M_{sko} + 0.82$) and the uncertainties are high ($\sigma = 0.22$).

Figure 6 shows the relation between M_L magnitudes given by EMSC and BEO (Serbia). 115 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure 6 shows the variation of M_L EMSC versus M_L BEO. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{EMSC} = 0.73\ M_{BEO} + 0.97 \pm 0.27. \tag{7}$$

M_{emsc} / M_{sko} relation is linear of the considered range of magnitudes ($2.0 \leq M_L \leq 4.4$).

The relation (7) indicates that the M_L magnitudes given by EMSC and BEO cannot be considered as equivalent ($M_{EMSC} = 0.73M_{BEO} + 0.97$) and the uncertainties are rather high ($\sigma = 0.27$).

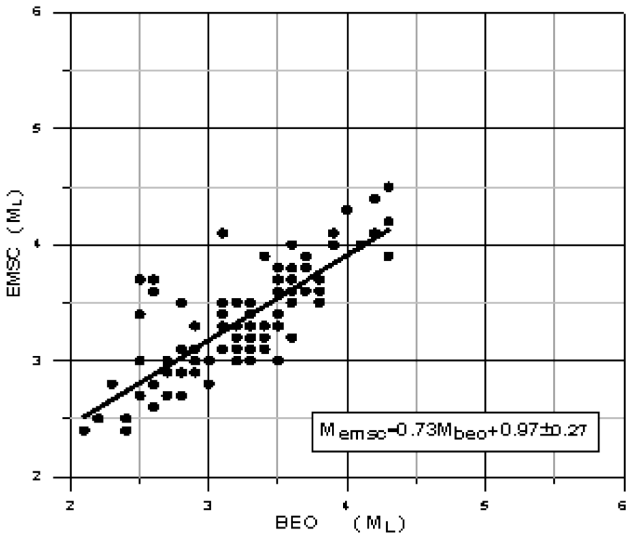

Figure 6. Correlation between ML from EMSC and ML from BEO (Serbia) for 115 shallow earthquakes. The straight line is the best fit.

Figure 7 shows the relation between M_L magnitudes given by EMSC and NOA (Greece). 189 events occurred in a spatial window of 40.0º - 44.5º N; 21.0º - 29.0º E were used. The diagram of Figure 7 shows the variation of M_L EMSC versus M_L NOA. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{EMSC} = 0.75\ M_{NOA} + 0.92 \pm 0.24. \tag{8}$$

M_{emsc} / M_{sko} relation is linear of the considered range of magnitudes ($2.2 \leq M_L \leq 4.5$).

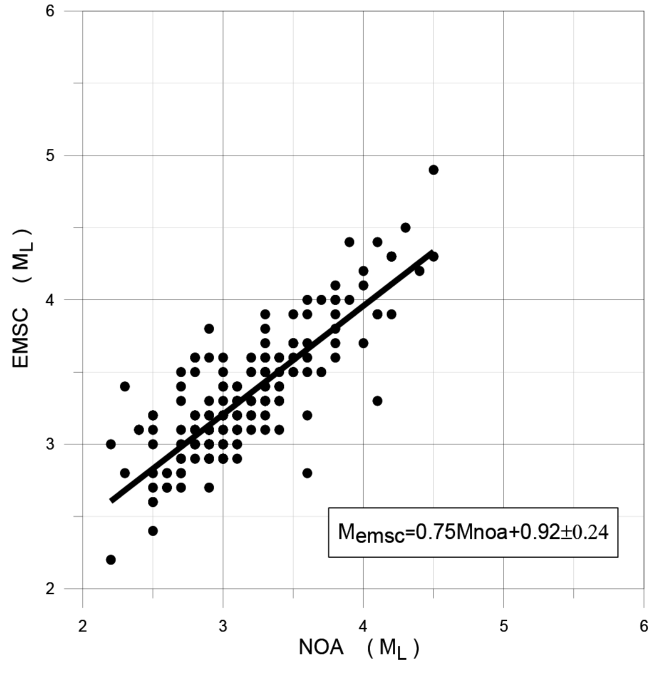

Figure 7. Correlation between ML from EMSC and ML from NOA (Greece) for 189 shallow earthquakes. The straight line is the best fit.

The relation (8) indicates that the M_L magnitudes given by EMSC and NOA cannot be considered as equivalent ($M_{EMSC} = 0.77\ M_{NOA} + 0.92$) and the uncertainties are high ($\sigma = 0.22$).

Second Stage

SOF (Bulgaria) magnitude estimates are compared with M_L reported by the other national centers: BUC (Romania), THE (Greece), KAN (Turkey), SKO (FYROM), BEO (Serbia) and NOA (Greece). The results are presented in Figure 8-13. The magnitude diferences between SOF - BUC, SOF - THE, SOF - KAN, SOF - SKO, SOF - BEO and SOF – NOA versus M_L SOF are presented in the figures.

The diagram of Figure 8 shows the variation of SOF - BUC, versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{BUC} = 0.1\ M_{SOF} + 0.40 \pm 0.45. \quad (9)$$

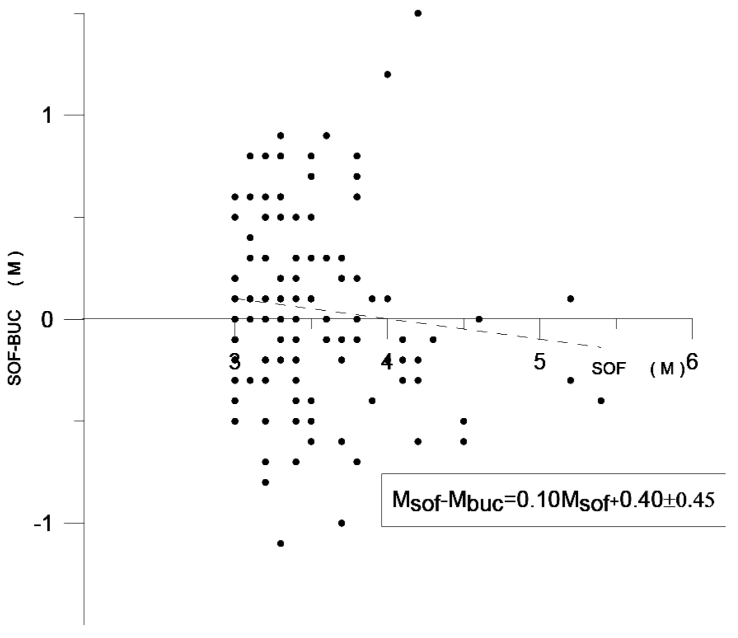

Figure 8. Correlation between magnitude diference SOF – BUC and ML from SOF for 88 shalow earthquakes in the magnitude interval interval 3.0≤ ML ≤ 5.4

As can be seen from the figure, the differences vary predominantly between -1 and +1. In the magnitude interval of 3.0 ≤M≤4.0 the differences are highly dispersed with almost equal number of positive and negative values. For magnitudes above 4.0, negative differences prevail, ie SOF magnitude estimates are lower than those of BUC. Overall, BUC (Romania) estimates are higher than the SOF estimates in the magnitude range considered (3.0≤ M_L ≤ 5.4). The relation (9) indicates that the M_L magnitudes given by SOF and BUC cannot be considered as equivalent and the uncertainties are high (σ = 0.45).

The diagram of Figure 9 shows the variation of variation of SOF - THE, versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{THE} = 0.03\ M_{SOF} + 0.08 \pm 0.36. \quad (10)$$

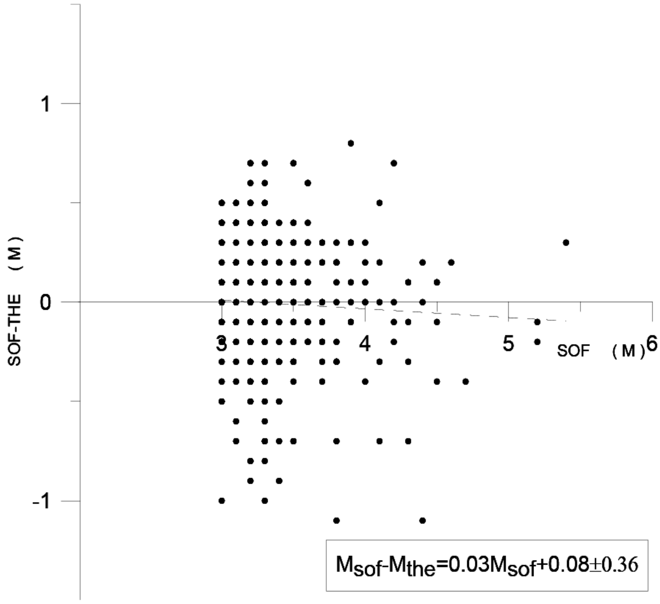

Figure 9. Correlation between magnitude difference SOF – THE and ML from SOF for 299 shalow earthquakes in the magnitude interval 3.0≤ ML ≤ 5.4

As can be seen from the figure, the differences vary predominantly between -1 and +1. In the magnitude interval 3.0 £M≤4.0 the differences are dispersed with almost equal number of positive and negative values. For magnitudes above 4.0, negative differences prevail, ie SOF magnitude estimates are lower than those of THE. The data dispersion decreases for magnitudes above 4.0, reaching a value of about 0.5.

The relation (10) indicates that the M_L magnitudes given by SOF and THE cannot be considered as equivalent and the uncertainties are high (σ = 0.36).

The diagram of Figure 10 shows the variation of SOF - KAN, versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{KAN} = 0.18\, M_{SOF} - 0.71 \pm 0.31. \qquad (11)$$

As can be seen from the figure, the differences vary mainly between -0.7 and +0.7. Overall, KAN (Turkey) estimates are higher than the SOF estimates in the magnitude range considered (3.0≤ M_L ≤ 5.4).

The relation (11) indicates that the M_L magnitudes given by SOF and KAN cannot be considered as equivalent and the uncertainties are high (σ = 0.31).

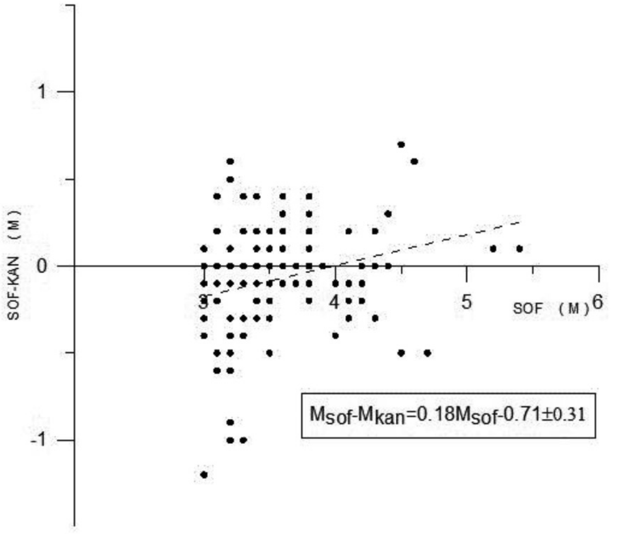

Figure 10. Correlation between magnitude difference SOF – KAN and ML from SOF for 105 shalow earthquakes in the magnitude interval interval 3.0≤ ML ≤ 5.4

The diagram of Figure 11 shows the variation of SOF - SKO versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{SKO} = 0.06\, M_{SOF} + 0.31 \pm 0.22. \qquad (12)$$

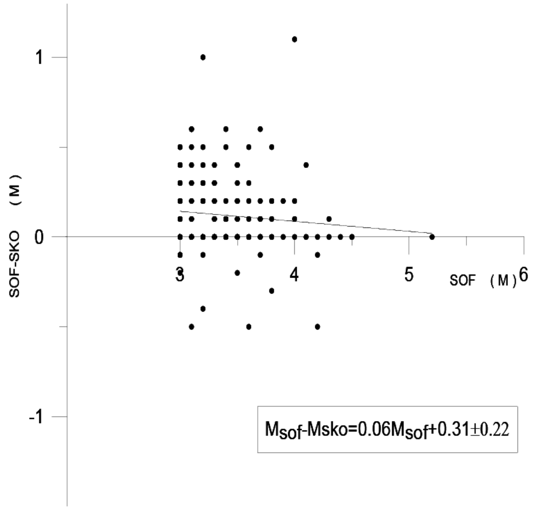

Figure 11. Correlation between magnitude difference SOF – SKO and ML from SOF for 115 shalow earthquakes in the magnitude interval interval 3.0≤ ML ≤ 5.4

As can be seen from the figure, the differences vary mainly between -0.7 and +1.0. For the considered magnitude interval 3.0 £M £5.4, the positive differences prevail, ie SOF magnitude scores are higher than those of the SKO.

The relation (12) indicates that the M_L magnitudes given by SOF and SKO cannot be considered as equivalent and the uncertainties are high (σ = 0.31).

The diagram of Figure 12 shows the variation of SOF - BEO, versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{BEO} = 0.21 \pm 0.39. \quad (13)$$

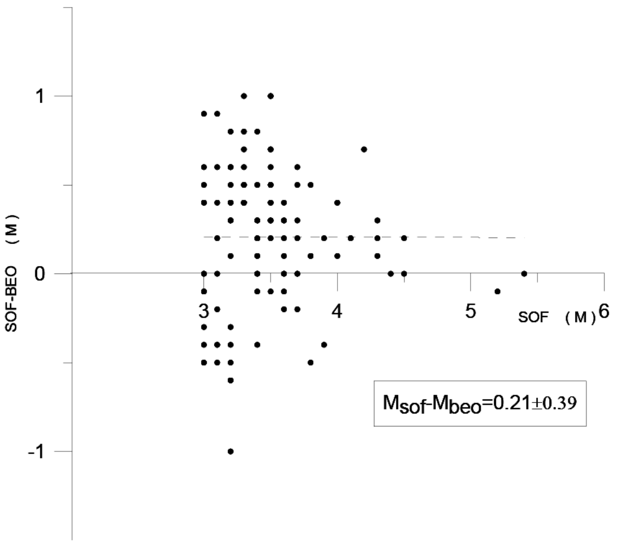

Figure 12. Correlation between magnitude difference SOF – BEO and ML from SOF for 115 shalow earthquakes in the magnitude interval interval 3.0≤ ML ≤ 5.4

As can be seen from the figure, the differences vary mainly between -1.0 and +1.0. The data dispersion decreases for magnitudes above 4.0. For the considered magnitude interval 3.0 £M £5.4, the positive differences prevail, ie SOF magnitude scores are higher than those of the BEO.

The relation (13) indicates that the M_L magnitudes given by SOF exceeded those of BEO by an average of 0.21 - a good match although the uncertainties are rather high (σ = 0.39).

The diagram of Figure 13 shows the variation of variation of SOF - NOA versus M_L SOF. The relation that expresses the best-fit line in the least squares'sense is:

$$M_{SOF} - M_{NOA} = 0.18 \pm 0.36. \quad (14)$$

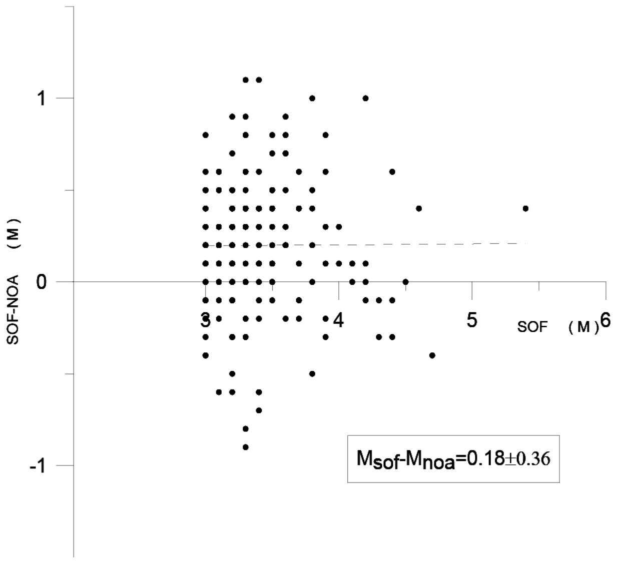

Figure 13. Correlation between magnitude difference SOF – NOA and ML from SOF for 189 shalow earthquakes in the magnitude interval 3.0≤ ML ≤ 5.4

As can be seen from the figure, the differences vary between -1 and +1. For the considered magnitude interval, 3.0 ≤M ≤5.0 the positive differences prevail, ie the SOF magnitude estimates are higher than those of NOA.

The relation (14) indicates that the M_L magnitudes given by SOF exceeded those of NOA by an average of 0.18 - a good match although the uncertainties are rather high (σ = 0.36).

Conclusion

The results of the study can be summarized in the following conclusions:

The closest to the M_L magnitudes given by EMSC are the M_L magnitudes reported by KAN (Turkish National Center) and SOF (Bulgarian National Center) although the uncertainties between M_L EMSC and M_L SOF are rather high (σ = 0.33);

The largest deviations from the M_L magnitudes reported by EMSC are observed for M_L magnitudes given by BUC (Romania) and BEO (Serbia);

M_L magnitudes given by NOA (Greece) and SOF are very close although the uncertainties are rather high (σ = 0.36). M_L magnitudes reported by SOF are slightly higher than those of SKO (FYROM) and BEO (Serbia) while the M_L magnitudes reported by BUC (Romania) and THE (Greece) exceed the M_L SOF (Bulgaria) in the considered magnitude range (3.0≤M≤5.4).

Acknowledgment. The work is supported by the program for career development of young scientists, BAS, Project DFNP-10 (2016–2017).

References:

Ambraseys N., 1988. Magnitude – fault length relationships for earthquakes in the Middle East, In: Historical Seismograms and Earthquakes of the World, Lee, W.H., Meyers, H. & Shimazaki, K. eds, Acad. Press Inc., 309-310.

Ambraseys, N., K. Simpson, J. Bommer, 1996. Prediction of horizontal response spectra in Europe, Earthquake Eng. and Struc. Dyn., 25(4), 371-400.

Ambraseys,. N., J. Douglas, S. K. Sarma,. and P. M. Smit, 2005.Equations for the Estimation of Strong Ground Motions from Shallow Crustal Earthquakes Using Data from Europe and the Middle East: Horizontal Peak Ground Acceleration and Spectral Acceleration. Bulletin of Earthquake Engineering, 3, 1–53.

Bonilla M., R. Mark J. Lienkaemper, 1984. Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement. Bull. Seism. Soc. Am., 74, p. 2379-2411.

Christoskov L., L. Dimitrova, D. Solakov, 2012. Magnitude determinations of P wave by digital broadband seismometers of NOTSSI network for local and regional events. Comptes Rendus de L‘Academie Bulgare des Sciences, 65 (5).

Department of Geophysics, Univ. of Thessaloniki, Greece, http://geophysics.geo.auth.gr/

EMSC, http://www.emsc-csem.org/Earthquake/

Gutenberg, B., C. Richter, 1936. Magnitude and energy of earthquakes, Science, 83, 183-185.

Gutenberg, B. C. Richter, 1956. Earthquake magnitude, intensity, energy and acceleration, Bull. Seismol. Soc. Am., 46, 105-145.

KOERI, Istanbul,Turkey,http://sismo.deprem.gov.tr/

Seismological Survey of Serbia Belgrad, Serbia

Seismological Observatory Skopje, FYR of Macedonia

Konstantinou, I.; G. Papadopoulos, A. Fokaefs, K. Orphanogiannaki, 2005. Empirical relationships between aftershock area dimensions and magnitude for earthquakes in the Mediterranean Sea region Tectonophysics, Volume 403, Issue 1-4, p. 95-115.

NIEPh, Bucarest, Romania, http://infp.ro/

NOTSSI, BAS, Sofia, Bulgaria, http://ndc.niggg.bas.bg/

Richter, C., 1935. An instrumental earthquake scale: Seismological Society of America Bulletin, 25, 1, p. 1-32.

Utsu T., Seki A. 1954. A relation between the area of aftershock region and the energy of mainshock. J. Seism. Soc. Japan, 7, 233-240.

Ризниченко Ю., 1976. Размеры очага корового землетрясения и сейсмический момент, Исследования по физике землетрясений, с. 9-27, Наука, Москва.

Връзки между MP и ML магнитудни скали

М. Попова

Резюме. Настоящата работата е фокусирана върху сравнение на магнитудните оценки за близки земетресения, определени от Българския сеизмичен център (SOF), с оценките на националните центрове в съседните балкански страни (Румъния – BUC, Сърбия – BEO, Македония – SKO, Гърция – THE и NOA и Турция – KAN) и Европейският средиземноморски сеизмичен център (EMSC). В проучването са използвани 372 земетресения, генерирани в пространствен прозорец: 40.0º – 44.5º N; 21.0º - 29.0º E, реализирани между 2007г. и 2011 г., в магнитуден интервал 3,0≤ ML ≤5,4 (долният праг на магнитудната оценка - M = 3,0 е определен в SOF).