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ROMANIAN EARTHQUAKES ANALYSIS USING THE BURAR SEISMIC ARRAY*

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Abstract. Bucovina seismic array (BURAR) is a medium-aperture array, installed in 2002 in the northern part of Romania (47.6148° N latitude, 25.2168° E longitude, 1,150 m altitude), as a result of the cooperation between the Air Force Technical Applications Center, USA and the National Institute for Earth Physics, Romania. The array consists of ten elements, located in boreholes and distributed over a 5×5 km^2 area; nine with short-period vertical sensors and one with broadband three-component sensor. Since the new station began operating the earthquake survey of Romania's territory it has been significantly improved. Data recorded by BURAR during the 01.01.2005 – 12.31.2005 time interval are first processed and analyzed, in order to establish the array detection capability of the local earthquakes, occurred in different Romanian seismic zones. Then a spectral ratios technique is applied in order to determine the calibration relationships for magnitude, using only the information gathered by the BURAR station. The spectral ratios are computed relatively to a reference event, considered representative for each seismic zone. This method has the advantage of eliminating the path effects. The new calibration procedure is tested for the case of Vrancea intermediate-depth earthquakes and proved to be very efficient in constraining the size of these earthquakes.

Key words: seismic array, BURAR, detection capability, spectral ratio.

INTRODUCTION

The purpose of this study is twofold: (*i*) analysis of the BURAR detection capability for the local intermediate-depth earthquakes from the Vrancea zone and the crustal events from different other seismic zones on the Romanian territory and (*ii*) estimation of the calibration relationship for magnitude using spectral ratios technique recorded only by the BURAR station.

A seismic array represents a set of seismometers with the recorded data integrated into a common scheme of acquisition and data processing. Array stations represent advanced systems for seismic monitoring characterized by high capability to detect and locate small-magnitude events since the array techniques of signal processing allow a significant increase of the signal-to-noise ratio.

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Starting with 2002 a new seismic monitoring station, BURAR (Bucovina Seismic Array), became fully operational in the northern part of Romania (see Fig. 1) in the framework of a bilateral collaboration between the Air Force Technical Applications Center (AFTAC), United States of America and the National Institute for Earth Physics, Romania.

BURAR consists of 10 seismic stations located in boreholes and distributed on a 5 km × 5 km area (see Fig. 2). Nine stations are equipped with short-period (SP) vertical sensors (GS-21 res) and one station is equipped with broadband (BB) three-component sensors (KS 54000). The broadband station (BURB) is located in the same place with the element number 8 of the array (BUR08).

BURAR DETECTION CAPABILITY

For this paper we limit our analysis to the 01.01.2005–12.31.2005 time interval. All the earthquakes occurred on the Romanian territory were considered.

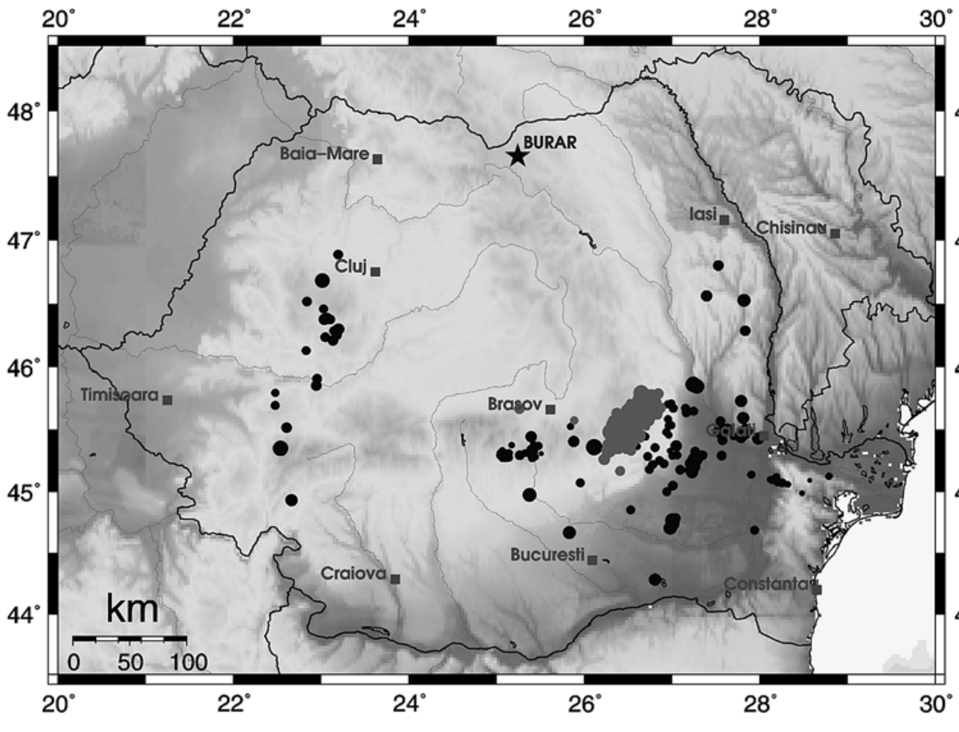


Fig. 1 – Romania's map and the BURAR location (black star). Grey dots are epicenters of Vrancea intermediate-depth earthquakes recorded during 2005; black dots are epicenters of crustal events occurred during 2005 in Romania. Dot size scales the event magnitude.

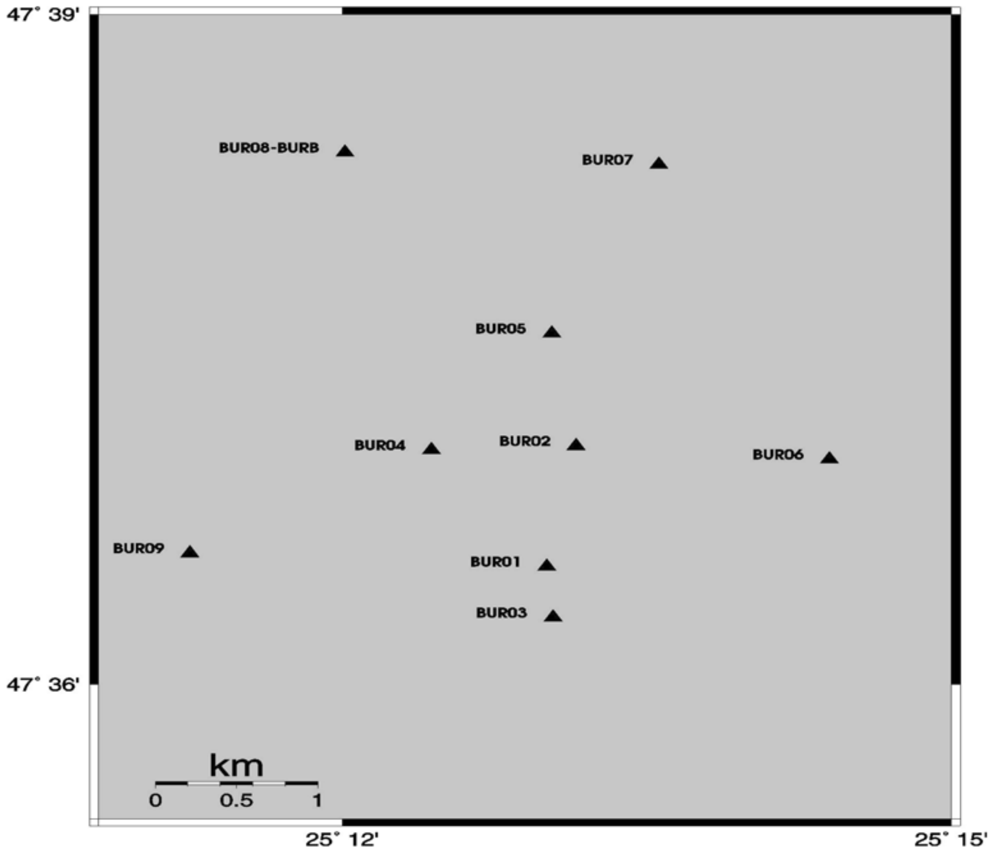


Fig. 2 – BURAR configuration, BUR01÷BUR09: SP sensors, BURB: BB sensor.

However, we have to rule out a few intervals: 20–21.03.2005, 15–17.07.2005, 06–08.08.2005, 09–31.10.2005, 01–09.11.2005 in which BURAR was out of work due to technical problems.

The contribution of each seismic zone to the seismic activity recorded on the Romanian territory is illustrated in diagram of Fig. 3. The diagram contains all the events located in the catalog regularly issued by the National Institute for Earth Physics – NIEP (ROMPLUS catalog, *Oncescu et al., 1999 – updated*) (629 events with magnitudes M_D between 1.2 and 5.8). As expected, the Vrancea region is contributing the most as number of events and energy. The relatively large numbers of events in Dobrogea and Făgăraș-Câmpulung zones are explained partly by the presence of industrial blasts in these areas.

An event is considered detected by BURAR if P phase is visible (S/N > 2) on at least one of the ten elements of the array. For the smaller events, a preliminary filtering is necessary to make visible the P or S phases (see Fig. 4 a,b).

In Fig. 5 we compare the distribution of Vrancea subcrustal events detected by BURAR against the events located in the ROMPLUS catalog. The detection is complete for magnitude $M_D > 4$ (or $M_w > 3.8$). For $M_D < 4$ the BURAR detection becomes poor (less than 50%) for lower magnitudes.

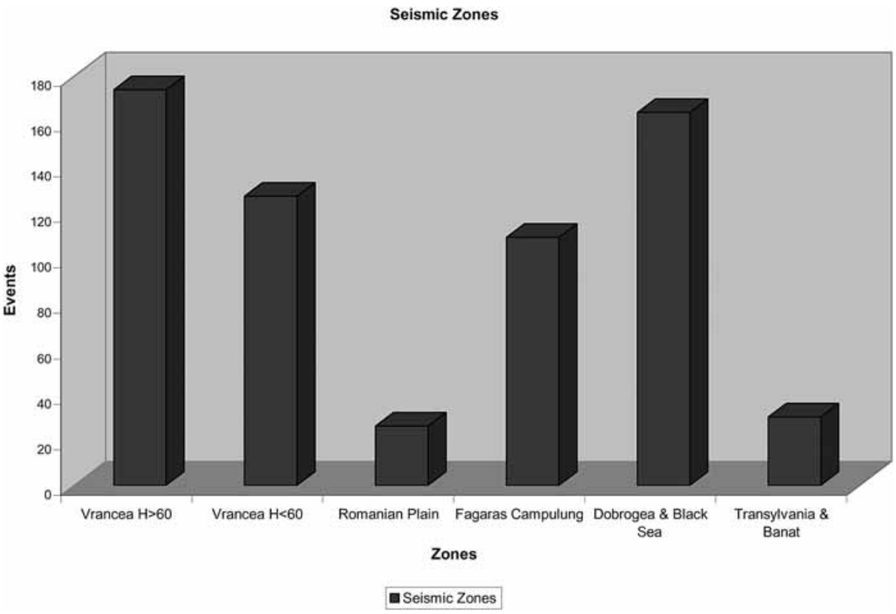


Fig. 3 – Distribution of the seismic activity for different zones.

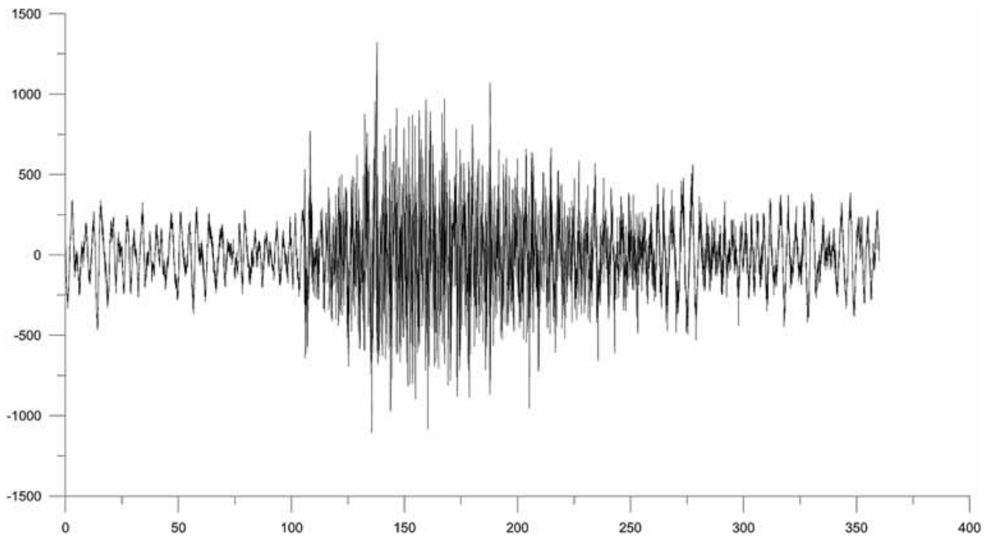
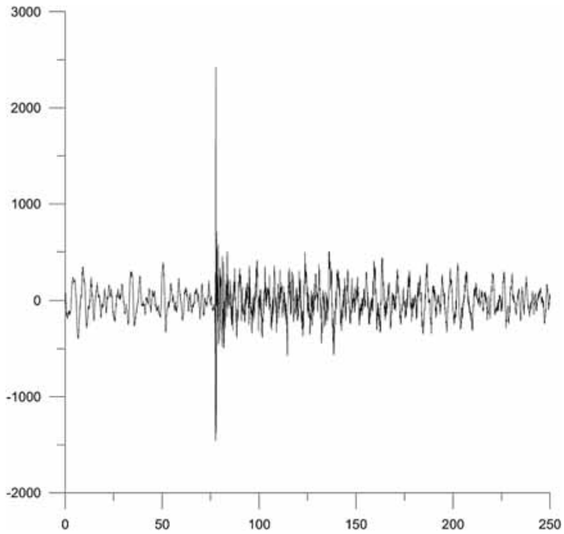


Fig. 4a – Example of earthquake at the limit of detectability with non-impulsive P-phase onset: April 4, 2005 (Vrancea, $M_w = 4.0$).

Fig. 4b – Example of earthquake at the limit of detectability with impulsive P-phase onset: December 26, 2005 (Vrancea, $M_w = 3.8$).



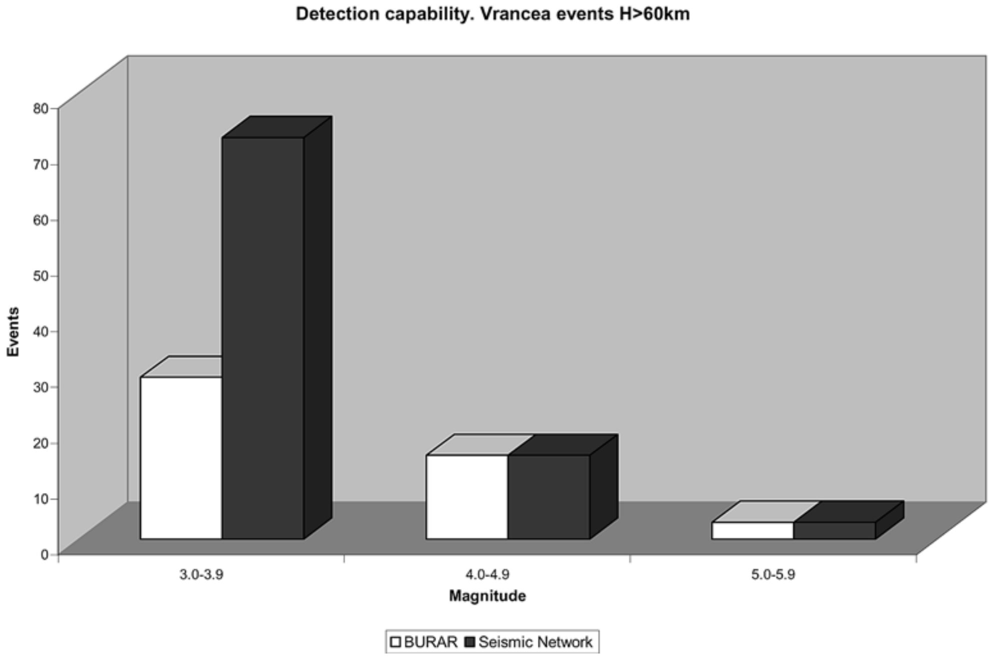


Fig. 5a – Detection test for Vrancea subcrustal earthquakes (H > 60 km): BURAR *versus* NIEP network. The magnitude is the duration magnitude (M_D). The relatively poor detection for $M_D < 4$ is due mainly to lower magnitude events (see Fig. 5b).

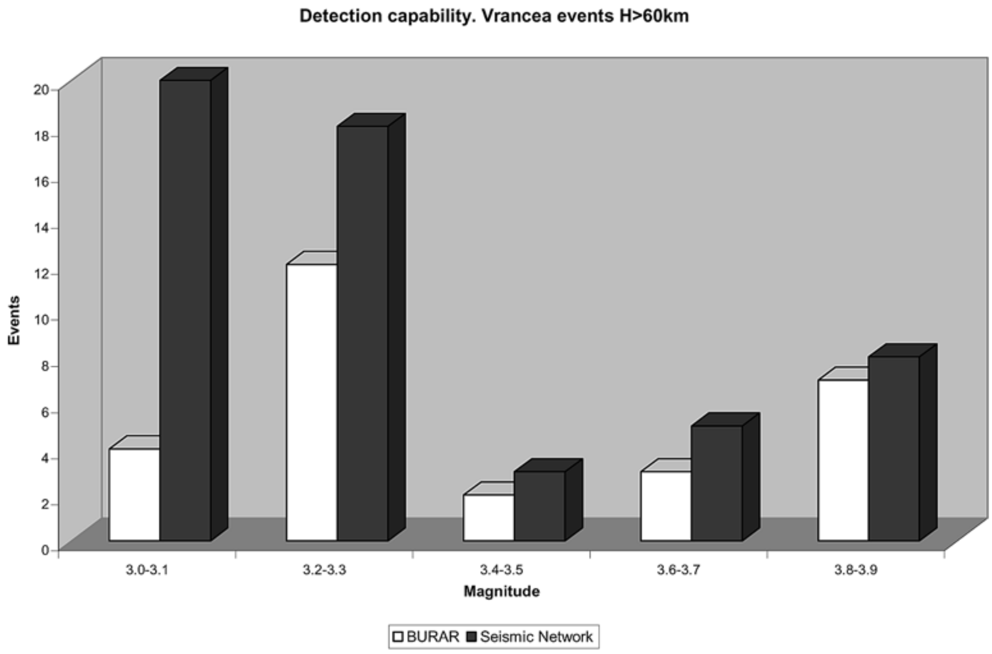


Fig. 5b – Detection test for Vrancea subcrustal earthquakes (H > 60 km): BURAR *versus* NIEP network. M_D is the duration magnitude.

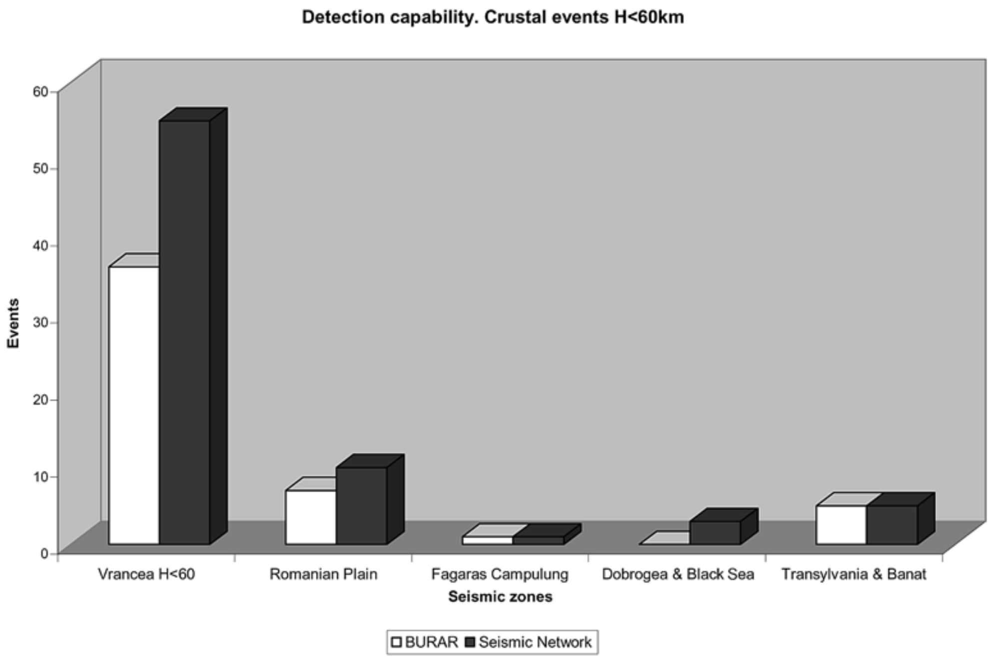


Fig. 6 – Crustal events (H < 60 km) detection for $M_D \geq 3$.

Analizing the BURAR detection capability for crustal events (Fig. 6) we notice a large variation from one seismic zone to another. The detection seems to be good for the events of the northern and western parts of the country, while it is poor for southern and south-eastern parts of the country. However, the events occurred in Dobrogea are smaller than in other seismic zones ($1.3 < M_D < 3.0$) and many of them are possibly explosions, with extrem high attenuation.

Our results on the BURAR detection capability are comparable with the previous analysis by *Ghica et al. (2004).*

MAGNITUDE CALIBRATION FOR VRANCEA INTERMEDIATE-DEPTH EARTHQUAKES

For the magnitude calculation we applied the spectral ratios technique (*Lindley, 1994, Popescu at al., 2003*). For this study we used 22 intermediate-depth earthquakes occurred during the 2002–2005 time interval. To apply the spectral ratios technique we select a reference event for which we know very well the source parameters. In our case, the reference event is the strongest earthquake produced in the study time interval (October 27, 2005, M_W = 5.9). Its waveform (vertical component) recorded on the broadband instrument is represented in Fig. 7.

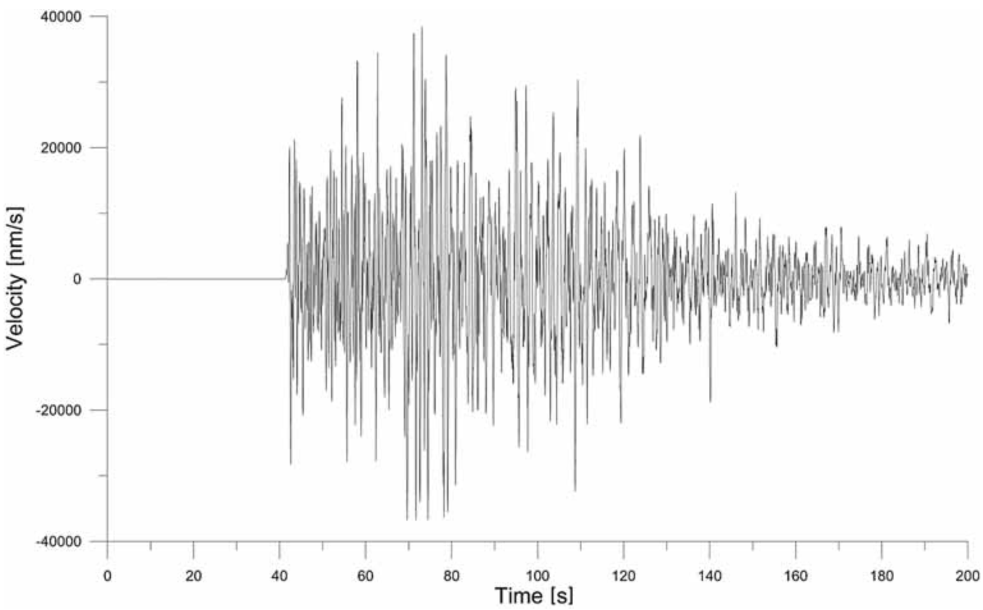


Fig. 7 – Seismic event of October 27, 2005 as recorded on the vertical component of the broadband station BURAR.

Spectra of all the other 21 events are divided to the reference spectrum separately for P waves, S waves (both NS and EW components): three ratios are obtained for each pair. Only the broadband records are used. The spectral ratios remove to a large extent the propagation and instrument effects. If the radiation pattern of the focal mechanism is not affecting essentially the spectral amplitude, then the spectral ratios will accurately reproduce the difference in magnitude between the analyzed event and reference event.

The moment magnitude is given by:

$$M_W = \frac{2}{3}(\log M_0 - 9.1) \tag{1}$$

and correspondingly the spectral ratio is given by:

$$\Delta Mw = 2/3 * \log r_i \tag{2}$$

where r_i represents the spectral ratio between event i and reference event and

$$\Delta Mw = Mw_i - Mw_{re} \tag{3}$$

The spectral amplitude is calculated after applying the instrument correction and the spectral ratios are estimated for all cases for the frequency interval 0.1–3 Hz. The comparison of the magnitude estimated from spectral ratios with M_w as determined in the ROMPLUS catalog shows a very good fit for both P-wave and S-wave records (see Fig. 8).

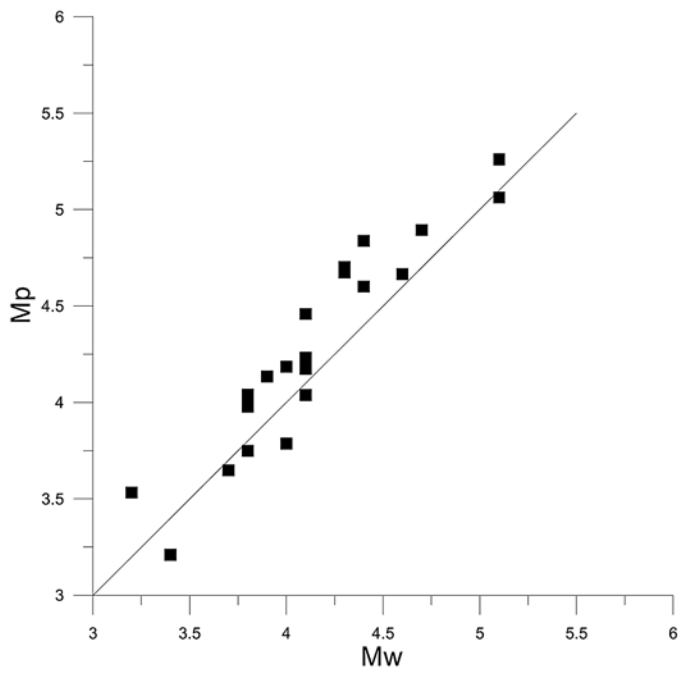
Our analysis demonstrates that we can estimate with acceptable precision the magnitude using only BURAR records. The residuals (see Fig. 9) are 0.1 ± 0.2 for both P and S waves and correspond with the usually admitted magnitude errors. Our results show that for the case of the BURAR station and Vrancea earthquakes the spectral ratios are sufficiently stable relatively to source magnitude showing no significant variation with the focal mechanism, depths and path effects. Therefore, the spectral ratios technique is proved to be a very efficient way to estimate rapidly and accurately the magnitude for Vrancea earthquakes.

The same technique will be applied for other stations of the NIEP seismic network (*e.g.*, TIRR, BMG, DRGR) to test the stability of the magnitude calibration and also will be extended to other seismic regions of the Romanian territory.

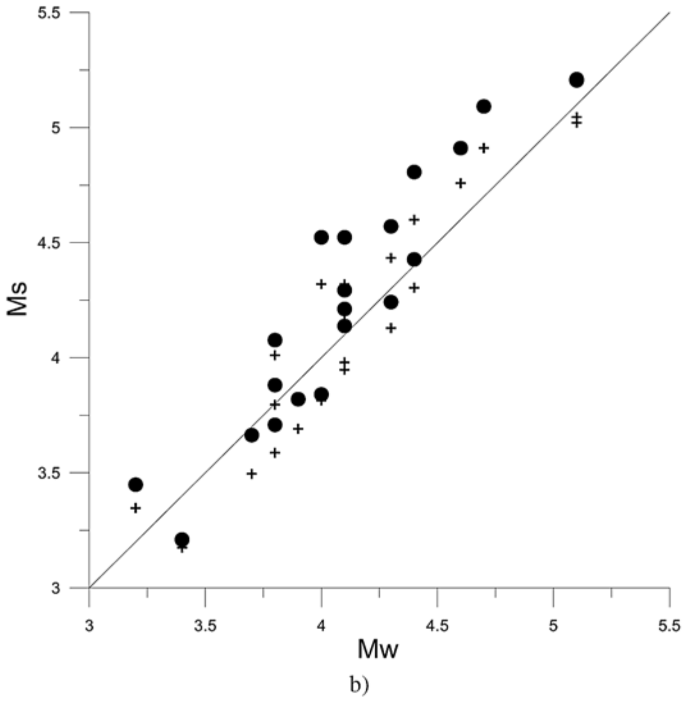
CONCLUSIONS

The test of the detection capability of the BURAR station for the earthquakes occurred on the Romanian territory in 2005 shows a rather variable capacity of detection depending on the particular seismic zone. The detection seems to be better for the case of crustal events produced in the Banat and Transylvania areas. In the case of Vrancea intermediate-depth earthquakes, the detection is strongly improved with the magnitude increase (detection is complete for $M_D > 4$).

Fig. 8 – Calibration of spectral-ratios magnitude with moment magnitude (M_w) (a) for P-wave spectral ratios (Mp) and (b) for S-wave spectral ratios (Ms) ● – NS component and + EW component.



a)



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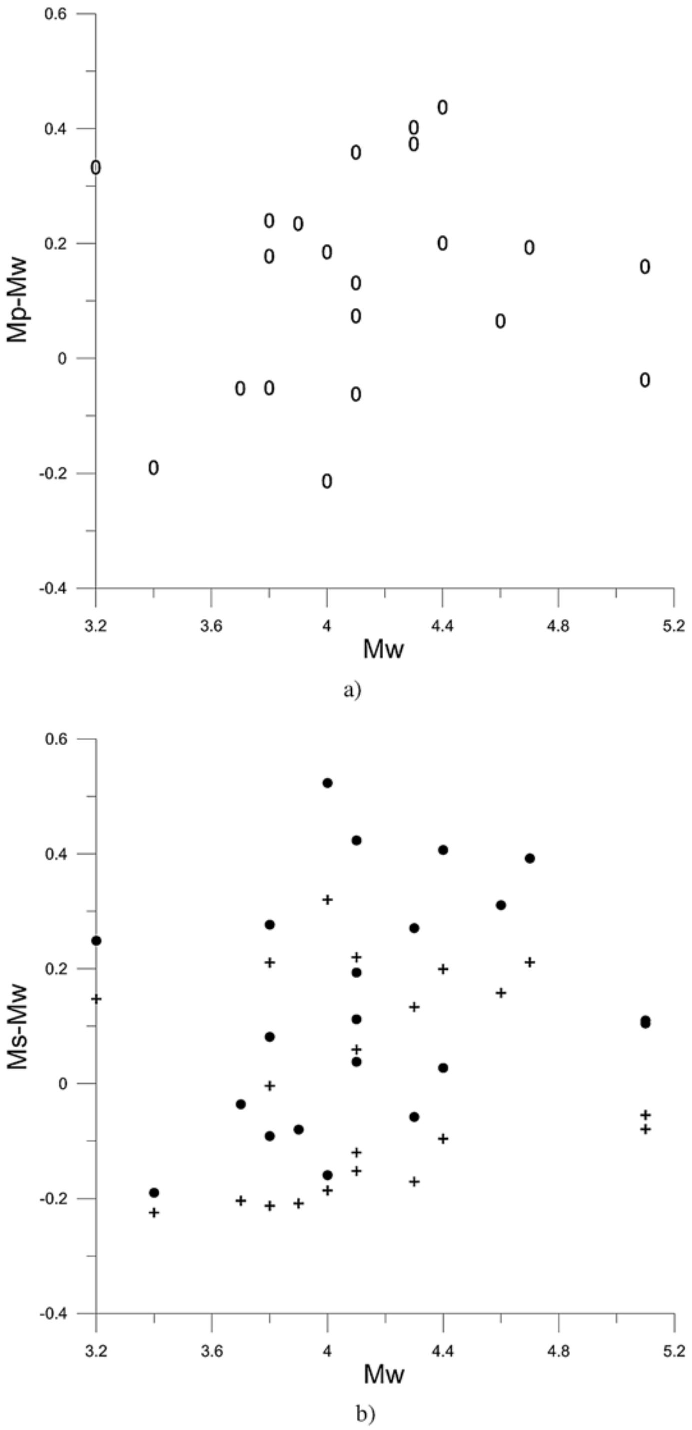

Fig. 9 – Mp (a) and Ms (b) residues 0 Mp – vertical component ● Ms – NS component + Ms - EW component.

On the basis of a data set of 22 earthquakes we demonstrate that the magnitude estimated using only BURAR records by a spectral ratios technique is matching very well the observed magnitude, no matter which, P or S, wave seismograms are used. Therefore, we propose a calibration relationship like

$$Mw_i = Mw_{ref} - 2/3 * \log r_i \tag{4}$$

where r_i represents the spectral ratio between event i and reference event. The reference event is the earthquake of October 27, 2005 ($M_w = 5.9$). The standard errors relatively to the magnitudes estimated by the routine procedure implemented for ROMPLUS catalogue are around 0.1.

It is likely that the P wave records (velocity) at BURAR will not be clipping in the case of Vrancea strong earthquakes, and therefore we can expect to extend the usefulness of the proposed magnitude calibration for larger events as well.

Since our results are encouraging, we shall extend our analysis to other seismic regions and other seismic stations.

Acknowledgements. These results are based on the data recorded by the BURAR array installed and maintained in the framework of the bilateral cooperation between the Air Force Technical Applications Center (USA) and the National Institute for Earth Physics (Romania).

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