GEOFIZIKA VOL. 43 2026

DOI: https://dx.doi.org/10.15233/gfz.2026.43.1
Original scientific paper

CC BY NC

The Baranja earthquakes of 1922 and 1924

Marijan Herak[1]* *and Davorka Herak*[2]

[1] University of Zagreb, Faculty of Science, Department of Geophysics (prof. emeritus), Horvatovac 95, 10000 Zagreb

[2] University of Zagreb, Faculty of Science, Department of Geophysics (retired), Horvatovac 95, 10000 Zagreb

Received 22 July 2025, in final form 27 September 2025

In regions of low seismicity, such as Baranja in northeastern Croatia, seismic hazard assessments rely heavily on the detailed characterization of the few largest known earthquakes. This study focuses on the two strongest historical earthquakes in the area, which occurred on 24 November 1922 and 12 August 1924. We re-evaluated these events using newly collected macroseismic data from Bosnia and Herzegovina, Croatia, Hungary, and Serbia. The number of intensity observations for the earthquake of 1922 was expanded from 106 to 278, whereas the previously macroseismically not analysed event of 1924 is described by 14 data points. Using a modified Kövesligethy-Jánosi model that accounts for intensity anisotropy in the epicentral area, we inverted the macroseismic fields to relocate the epicentres and estimate focal depths and magnitudes. Both events were relocated near the village of Zmajevac, within the Bansko Brdo tectonic unit, close to its boundary with the Drava depression. The 1922 epicentre moved 13 km north-northeast of the original location in the Croatian Earthquake Catalogue (CEC), while the 1924 epicentre shifted 22 km westward. Revised moment magnitudes are M_{wm} 5.3 and M_{wm} 4.4 for the 1922 and 1924 events, respectively. Estimated focal depths are shallower than previously listed: 11 km and 8 km, compared to the 18 km and 14 km in CEC. These results indicate that significant seismicity in Baranja is confined to the Bansko Brdo unit, with no evidence of strong earthquakes or faults with sufficient seismogenic potential in the Drava Depression or Northern Baranja–Bačka units. This has important implications for regional seismic hazard estimates. Furthermore, we find no instrumental support for the largest catalogued aftershock of the 1922 event and propose its removal. Finally, we interpret the 1924 earthquake as a late aftershock of the 1922 mainshock, suggesting a dependent relationship between the two.

Keywords: macroseismic field inversion, seismicity of Baranja, earthquake sources in Baranja, historical earthquakes, earthquake hazard

1. Introduction

The geographical and historical region of Baranya is situated within the Pannonian Basin and is currently divided between Hungary and Croatia. The larger, northern portion lies within Hungary, while the southern part – referred to as Baranja – is located in Croatia. It is bounded by the Drava and Danube rivers and the Croatian-Hungarian border (see Fig. 1).

In seismological studies, Baranja is frequently considered in conjunction with the neighbouring Croatian region of Slavonia. Slavonia extends east of Virovitica and is delineated by the Sava river to the south and the Drava and Danube rivers to the north (see Fig. 2). In the east it borders Western Syrmia where seismicity is very low. This grouping is justified by the comparable characteristics of these two regions in terms of seismicity, seismic hazard (Herak et al., 2011), geological structure, and tectonic setting (e.g. Schmid et al., 2020).

As illustrated in Fig. 1, earthquake activity in Slavonia and Baranja is notably lower than in seismically more active regions such as the Central External Dinarides or north-western Croatia. Nevertheless, consistent with the nature of intraplate seismicity, the historical seismic record for the region includes occasional moderate-to-strong events (Fig. 2). The most active zones correspond to the hilly terrains of Bilogora Mt., the Slavonian Mts., and Moslavačka Gora. These regions have experienced multiple earthquakes with maximum intensities reaching degree VIII on the European Macroseismic Scale (EMS-98, Grünthal et al., 1998; hereafter EMS), as shown in Fig. 2.

1.1. Most important earthquakes in Slavonia

The chronology of felt earthquakes in Slavonia, based on protocols and records from Franciscan monasteries between the mid-18th and mid-19th centuries, has been documented by Penzar (1982) and Gregl et al. (2021), with additional information available in Kišpatić (1891). These sources provide valuable insights into earthquake effects observed in monasteries located in Bač, Našice, Osijek, Slavonski Brod, Šarengrad, and Vukovar. However, the available documentation is generally insufficient for accurately locating or quantifying most of these events. It is therefore noteworthy that, to our knowledge, no comprehensive study of the seismicity of Slavonia and Baranja has been conducted, and only two earthquakes have been described in detail in dedicated publications.

The first of these occurred on 24 March 1884 near Đakovo and was extensively documented by Pilar (1886) in a remarkable monograph describing his observations during the visit to the shaken area. The strongest effects were reported in Đakovo itself and in the nearby villages, where most chimneys collapsed and house walls cracked. The Croatian Earthquake Catalogue (CEC hereafter; Herak et al., 1996; last updated in 2024) lists the epicentral intensity as I_0 = VII MSK.

The second event, which remains the strongest instrumentally recorded earthquake in Slavonia, occurred on 13 April 1964 just north of Slavonski Brod in the complex of Slavonian Mountains. According to the CEC, it had a magnitude of $M_L = 5.65$ and a maximum intensity of $I_{max} =$ VIII MSK. Various aspects of this earthquake were described by Cvijanović and Skoko (1964), Mileta (1966a,b), and Josipović Batorek (2013). Reports indicate that there were two fatalities and 60 people were injured. Approximately 2000 houses were damaged, forcing around 10000 residents to take temporary shelter in tents.

Notable among historical events are also the earthquakes of 1757 near Virovitica. The sources (*e.g.* contemporary accounts of I. Josipović as reported in

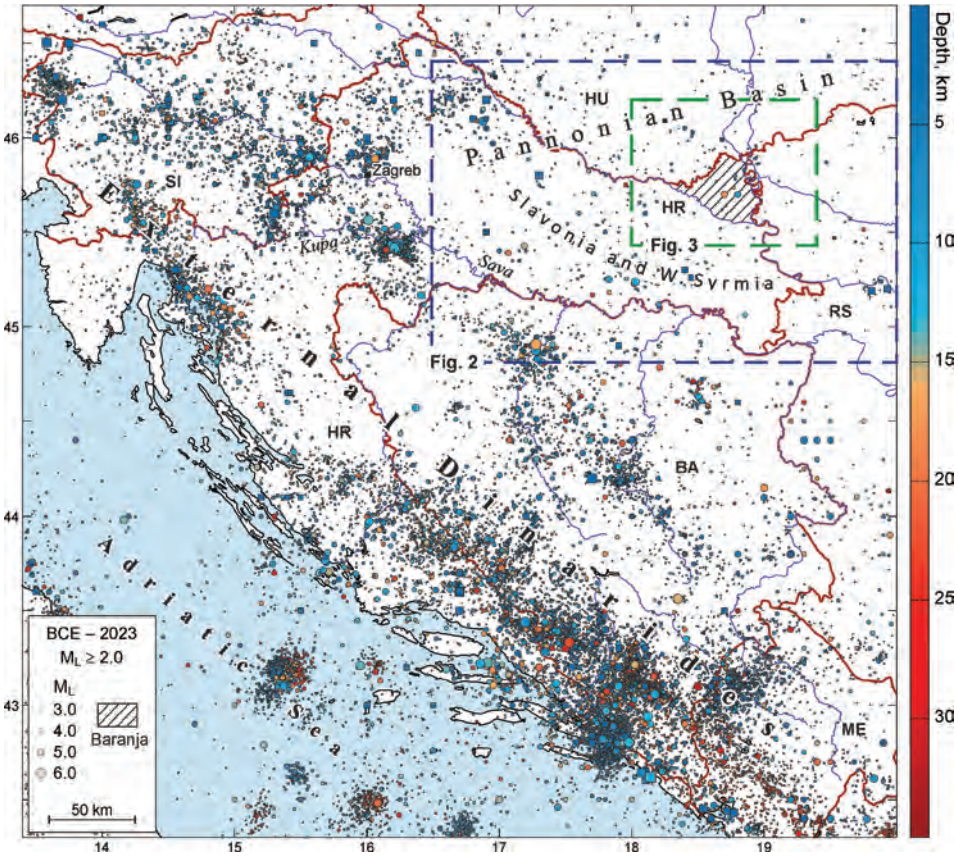


Figure 1. Seismicity of Croatia and surrounding regions for local magnitude $M_L \geq 2.0$. The symbol size scales with magnitude, and their colour indicates focal depth. The blue and green dashed rectangles show the extents of Figs. 2 and 3, respectively. After the Croatian Earthquake Catalogue (CEC, Herak et al., 1996, last updated in 2024) and Czecze et al. (2023) for earthquakes in Hungary. BA – Bosnia and Herzegovina, HR – Croatia, HU – Hungary, ME – Montenegro, RS – Serbia, SI – Slovenia.

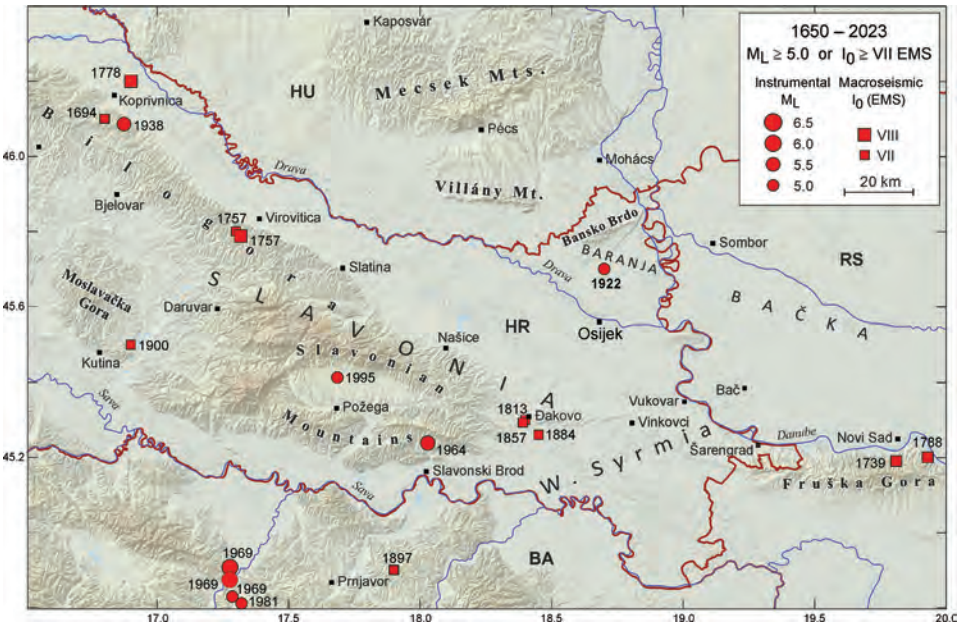


Figure 2. Earthquakes in the period 1650–2023 with $M_L \geq 5.0$ (red circles) or $I_0 \geq$ VII EMS (red squares) in Slavonia, W. Syrmia and Baranja and their immediate neighbourhood. Year of occurrence is shown next to the respective symbol. See the blue dashed rectangle in Fig. 1 for geographical position, and caption to Fig. 1 for country abbreviations. After Croatian Earthquake Catalogue (CEC, Herak et al., 1996, last updated in 2024).

Horvat, 1913; Krčelić, 1952; see also Kišpatić, 1891) state that a foreshock occurred on 27 June (I_{max} = VII MSK), followed by the mainshock on 7 (or possibly 8) July (I_0 = VIII MSK). The earthquakes caused severe damage in Virovitica, particularly to the Franciscan convent, which was rendered uninhabitable. The mainshock produced violent shaking and caused church bells to ring, ground fissures with water and yellow sand emerging from them, and caused the deepest wells to overflow. Virovitica is described as appearing "like after a battle". Cracks appeared in the vault of the Franciscan church in Kloštar Ivanić (75 km away). The sanctuary vault of the Zagreb Cathedral (around 110 km from the epicentre) was also damaged, with several chimneys collapsing in the city. The tremors were also felt in southern Hungary, in the Pécs region. Records mention 54 aftershocks during the first two months of activity.

1.2. Most important earthquakes in Baranja and its surroundings

Fig. 3 presents seismicity of Baranja and its immediate vicinity for events from the period 1835–2023, and $M_L \geq 1.0$, regardless of the completeness thresh-

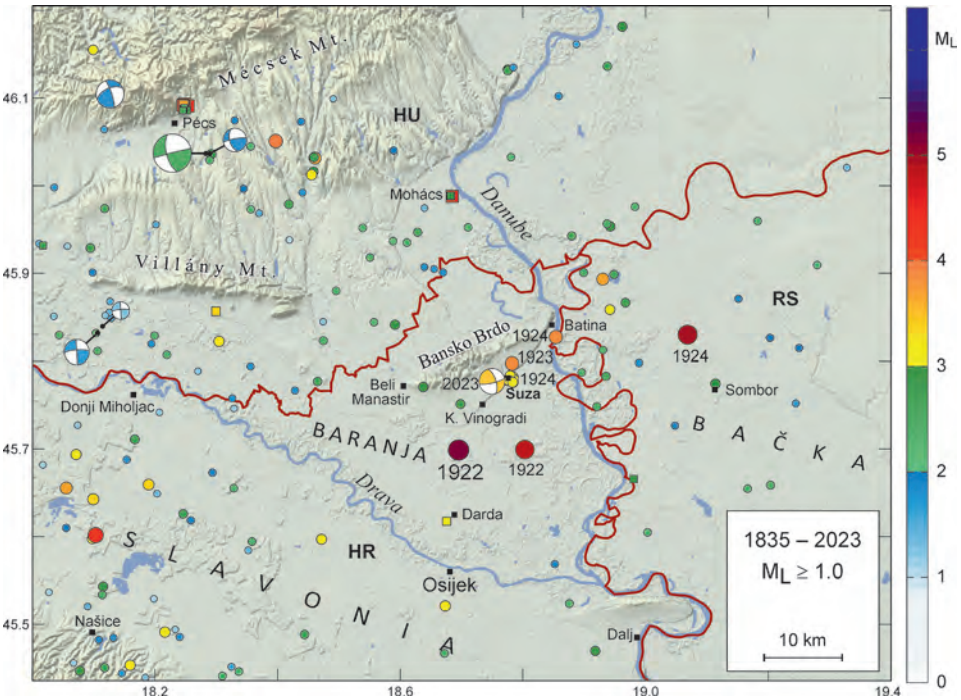


Figure 3. Seismicity of Baranja and the neighbouring regions, 1835–2023, $M_L \geq 1.0$ after CEC (Herak et al., 1996, last updated in 2024) and Czecze et al. (2023) for earthquakes in Hungary. Focal mechanisms are shown by stereographic lower-hemisphere projection of the best double-couple solution after Békési et al. (2023) for events in Hungary whereas the one in 2023 in Baranja is the revised solution from the CroFMS database (Herak, 2024). The compressive quadrants are coloured to show the respective magnitude according to the colour scale. See the green dashed rectangle in Fig. 1 for geographical position, and caption to Fig. 1 for country abbreviations.

old of the used catalogues. In Hungary, seismicity is mostly related to the Mécsek and Villány Mountains. All available focal mechanisms indicate strike-slip faulting, probably along sinistral faults that are mostly parallel to the main topographic features striking E–W to ENE–WSW.

Earthquakes in north-western Bačka region of Serbia are also infrequent and mostly weak. The only exception in Fig. 3 is the earthquake of 1924 (one of the targets of this study), which CEC, BSHAP2 and EMEC2021 catalogues, report close to Sombor (Table 1). It will be shown in section 4 that this location is most probably false, and the earthquake actually occurred in northern Baranja.

In Baranja itself (Fig. 3), seismicity remains generally low. The only significant seismic episode recorded in the region began with the largest known earthquake to have occurred there – the event of 24 November 1922 (Table 1), which

is the primary focus of this study[1]. Catalogues also report a strong apparent aftershock (M_L 4.8) located just east of the 1922 mainshock, as well as a cluster of events near the village of Suza on the southern slopes of Banovo Brdo (also known as Baranja Mountain). These include an early 1923 aftershock, a series of aftershocks following the 1924 earthquake, and a more recent low-magnitude event (5 January 2023, M_L 3.4) – the only earthquake in Baranja for which the first-motion polarity focal mechanism is available.

This most recent event is listed in the CroFMS database (Herak, 2024) with a prevalent dip-slip solution. However, upon re-examining the available data – now including many seismograms from Hungary recorded by the Z6 temporary network (AdriaArray project, DOI: https://doi.org/10.7914/2cat-tq59), which were not available immediately after the 2023 earthquake – additional polarity readings were incorporated into the inversion. This revision yielded a new focal mechanism solution, presented in Fig. 3: a strike-slip mechanism featuring a sinistral nodal plane striking WSW–ENE. It is consistent with solutions reported nearby in Hungary by Békési et al. (2023) and aligns reasonably well with the structural trend of Banovo Brdo (Fig. 3). Likewise, the P-axis striking SW–NE is in excellent agreement with the direction of the interpolated maximum horizontal stress (S_{Hmax}) in Baranja after Békési et al. (2023).

Were it not for the 1922–1924 earthquakes (Table 1), and given the lack of data on local active faults, the seismic hazard in this region would be entirely determined by events originating outside of Baranja. Although the macroseismic dataset for the 1922 earthquake was relatively extensive (see Section 2.1), reported epicentral locations from various sources are distributed along a linear trend approximately 25 km in length, oriented in the NNE–SSW direction (see inset in Table 1). This spatial spread is also reflected in the associated standard errors. A similar pattern is observed for the 1924 earthquake, though in this case, the reported epicentral locations are dispersed primarily in the E–W direction. Reported magnitude estimates for the 1922 event range from 4.6 to 5.3, while those for the 1924 event range from 4.6 to 5.1. It thus seems reasonable to extract as much information as possible from all available data on these earthquakes, in the hope of better constraining their locations and magnitudes.

2. Inversion of the observed intensities – the KJE method

The source parameters – epicentral coordinates (φ, λ), focal depth (h), and epicentral intensity (I_0) – were inverted for using the set of estimated intensities (intensity data points, IDPs) by the modified method based on the Kövesligethy–Jánosi formula (Kövesligethy, 1906, 1907; Jánosi, 1907):

[1] This earthquake also marked the onset of the most seismically active period in and around Croatia over the past two centuries – between 1922 and 1927 six important earthquake sequences occurred with mainshock magnitudes ranging from M_L 5.1 to M_L 6.2 (Herak and Herak, 2024), thus activating epicentral areas of Baranja, Imotski–Tihaljina, Šibenik, Vinodol Channel, Nevesinje, and Brežice.

$$I_i = I_0 - k \log(r_i/h) - k\,\alpha\,\mu\,(r_i - h), \quad (1)$$

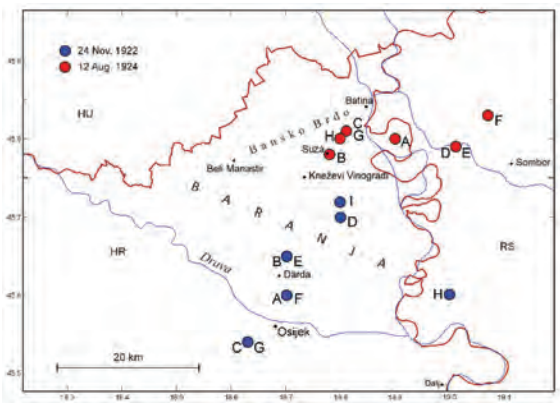
where I_i is the intensity observed at hypocentral distance $r_i = (d_i^2 + h^2)^{1/2}$, d_i is epicentral distance, h is focal depth, I_0 is the epicentral intensity, k is the isoseismal coefficient (typically between 2 and 4, commonly around $k = 3$, *e.g.* Musson, 2009)

Table 1. Parameters of the earthquakes of 1922 and 1924, as given by various sources. S – source, h – depth, I_0 – epicentral intensity, I_{max} – maximum observed intensity, M – magnitude, MSK – Medvedev-Sponheuer-Kárník, RF – Rossi-Forel, MS – Mercalli-Sieberg. The inset in the last row shows epicentral locations for the two events.

S	Time (UTC)	Lat. °N	Lon. °E	h, km	I_0 (I_{max})	M
			Earthquake: 24 November 1922			
A	02:15:40 ± 15 s	45.6±0.3	18.7 ± 0.3	18 ± 3	7.0 ± 0.5 MSK	M_{LH} 5.3±0.3
B	02:15:40 ± 10 s	45.65 ± 0.10	18.70 ± 0.10	13 ± 3	7.5 ± 0.5 MSK	M_S 5.3±0.3
C	02:15:40	45.54 ± 0.18	18.63 ± 0.25	10	7.0 MSK?	M_L 4.8, M_S 5.3
D	02:15:40	45.7	18.8	18	–	M_L 4.9, M_w 4.6
E	02:15:40	45.65	18.70	12.6	(VII–VIII) MSK	M_w 5.1
F	02:15:74*	45.6 ± 0.2	18.7±0.3	18	7.5 MSK	M_L 5.1
G	02:15:40	45.54	18.63	21	–	M_L 5.4
H	02:15:40	45.6 ± >0.4	19.0 ± >0.4	crust	VIII MS	M_{LH} 5.3
I	–	45.72	18.80	–	VIII RF	–
			Earthquake: 12 August 1924			
A	16:27:25 ±10 s	45.8 ± 0.3	18.9 ± 0.3	7 ± 3	7 ± 1 MSK	M_{LH} 4.9 ± 0.3
B	16:27:31	45.78 ± 0.10	18.78 ± 0.10	19 ± 3	6.0 ± 0.2 MSK	M_S 4.9 ± 0.3
C	16:27:50	45.81	18.81	12	7.0 MSK?	M_S 4.9
D	16:27:25	45.79	19.01	10	–	M_L 4.9, M_w 4.6
E	16:27:25	45.79	19.01	8	7.0 MSK	M_m 4.5, M_w 4.9
F	16:27:25	45.83 ± 0.23	19.07 ± 0.33	14	7 MSK	M_L 4.9
G	16:27:50	45.81	18.81	12		M_L 5.1
H	15:27:50	45.8 ± >0.4	18.8 ± >0.4	crust	VI MS	M_{LH} 4.9

A – Shebalin et al. (1974);
B – Shebalin et al. (1998);
C – Zsíros (2000);
D – EMEC2021 (Lammers et al., 2023);
E – BSHAP2 (Markušić et al., 2016);
F – CEC (Herak et al. 1996, updated in 2025);
G – Czecze et al. (2023);
H – Kárník (1969)
I – Gilić (1923).

*A misprint in the catalogue!



controlling the spacing of isoseismals, α is the intensity attenuation coefficient, and $\mu = \log(e)$. The original formulation (1) is hereby modified to account for the frequently observed elongation of the innermost isoseismals:

$$I_i = I_0 - k \log(R_i/h) - k\,\mu\,\alpha(R_i - h), \tag{2a}$$

$$R_i = (D_i^2 + h^2)^{1/2}, \quad D_i = d_i / c(\phi_i, \gamma, \varepsilon, d_{el}). \tag{2b}$$

In this version, the anisotropy of the macroseismic near field is formally introduced by modifying the epicentral distance d_i by an elliptical correction c, resulting in a reduced epicentral distance D_i (see Appendix for more detail). This approach will be referred to as the Kövesligethy – Jánosi elliptical model or the KJE model.

The correction c depends on the azimuth of the IDP (ϕ_i), the azimuth (γ) of the long axis strike, the isoseismal ellipticity (ε) in the epicentre, and the epicentral distance beyond which the medium is considered isotropic (d_{el}). The ellipticity ε is modelled to decrease with distance, tending toward $\varepsilon = 1.0$ as d_i approaches d_{el}. The three additional parameters ε, γ, d_{el} may be kept constant if reasonable values are known, or can also be inverted for. The same holds for k and α in (1). Here we fix only $d_{el} = 30$ km, which ensures that substantial anisotropy is kept only near the meizoseismal area. The rest of parameters are inverted, thus increasing the number of unknown parameters to eight: φ, λ, h, I_0, k, α, ε, γ. To avoid results that are not consistent with the expected properties of seismicity and intensity attenuation, we limit some of the parameters to the intervals normally observed in Croatia. Those are: $h \in [2, 20]$, $\varepsilon \in [1, 2.5]$, and $k \in [2, 4]$.

The best fitting parameters are sought for in two stages. In the first stage a guided grid search is performed in order to identify the neighbourhood of the global minimum of the misfit function:

$$q = \frac{1}{\sum w} \sum_{i=1}^{N} w_i (I_{obs,i} - I_{cal,i})^2 \tag{3}$$

where $I_{obs,i}$ is the observed intensity at the i-th IDP, $I_{cal,i}$ is the intensity computed by (2) at the same IDP and rounded to the same precision as $I_{i,obs}$ (*i.e.* 0.5 EMS here), and w_i is the weight depending on $I_{obs,i}$ and the epicentral distance (d_i):

$$w_{I,i} = \left(\frac{1}{I_{max} - I_{obs,i} + 1} \right)^m$$

$$w_{D,i} = \begin{cases} 3, & \text{for } d_i \le 12 \text{ km} \\ \cos\left[\dfrac{\pi(d_i - 15)}{35} \right] + 2, & \text{for } 12 \text{ km} < d_i < 35 \text{ km} \\ 1, & \text{for } d_i \ge 35 \text{ km} \end{cases} \tag{4}$$

$$w_i = w_{I,i}\, w_{D,i}.$$

The weighting scheme proposed in (4) is designed to assign greater weight to higher intensity values and to observations near the epicentral region. The exponent m controls the rate at which the weights decrease with decreasing intensity. In this study, we adopt a moderate value of $m = 0.5$.

The second stage is a pure Monte Carlo search involving 350000 random trials in the vicinity of the best solution found so far. The candidate solutions are sampled from normal distributions centred on the current best solutions with their standard deviations getting progressively smaller towards the end of this stage.

One of the key advantages of performing a grid search combined with Monte Carlo sampling of the parameter space is that it yields values of the misfit function q across the entire parameter space of interest. This enables the identification of a subset of solutions for which q falls below a chosen confidence threshold p. To achieve this, all misfit values q_i are normalized by the minimum misfit value q_0, yielding normalized values $Q_i = q_i/q_0$. The threshold for Q corresponding to the desired significance level p is then determined using the inverse cumulative distribution function of the F-distribution, $F^{-1}(p, N-n, N-n)$, where both the numerator and denominator have $N-n$ degrees of freedom. (*e.g.* Mayeda et al., 1992; Bianco et al., 2002; Herak, 2008; Stipčević et al., 2011). Here, N is the number of IDPs used in inversion, and m is the number of free model parameters. Although we invert for eight parameters, we set $n = 7$, since the parameter I_0 is determined by imposing the condition that the average weighted residual must equal zero.

3. Earthquake of 24 November 1922

3.1. Macroseismic data

Macroseismic data were collected from various sources, listed below in the order of preference:

A. Questionnaires from the Macroseismic data archive of the Department of Geophysics, Faculty of Science, University of Zagreb – intensities were evaluated in the course of this study according to the EMS scale. As Baranja was not part of Croatia at that time, the questionnaires from the archive in Zagreb unfortunately do not contain reports from the epicentral area.

B. Various reports, newspaper articles, chronicles, *etc.* Intensities were estimated in the course of this study according to the EMS scale.

C. Digitized intensity map from the *Atlas of isoseismal maps* compiled by Shebalin (1974) with 88 intensity points from Croatia (Mercalli-Cancani--Sieberg scale, MCS) and 18 intensity points from Serbia (FM-M – Forel--Mercalli scale modified by J. Mihailović);

D. Hand-written manuscript table from the Institute of Seismology in Belgrade, Serbia (IoS-BEO, 1922a) with intensities estimated according to an unknown intensity scale (possibly RF-M, the J. Mihailović's version of the Rossi-Forel scale. Maximum intensities were estimated as VIII$^+$ RF-M(?); '(?)' here forth denotes uncertain macroseismic scale assignment);

E. Macroseismic Seismological Bulletin of the Institute of Seismology in Belgrade, Serbia, (IoS-BEO, 1922b) reporting only the 10 highest intensities from the epicentral area (all equal to VII), probably converted from the values given in the manuscript (D) into FM-M or MCS-M (J. Mihailović's versions of the Forel-Mercalli and Mercalli-Cancani-Sieberg scales).

The major difficulty was conversion of many intensities estimated in IoS-BEO (1922a) (item D above) to the EMS scale. The actual scale used was not stated in the document, and we learn from Shebalin et al. (1974), that at least three different scales were used at different times. All of them were based on an international standard scale but modified in an undocumented way by the Institute's director Prof. J. Mihailović. It is unfortunate that it seems that the change from prevalent usage of FM-M to MCS-M occurred in the period 1922–1923 (Shebalin et al, 1974), so it is not clear how to unequivocally interpret neither the manuscript (D; IoS-BEO, 1922a) nor the data in the published bulletin (E; IoS-BEO, 1922b).

We therefore compared our independent intensity estimates in the EMS scale (items A and B above) with intensities for the same localities assigned in the manuscript (D), for all instances where such pairs existed, consulting also the conversion diagrams shown in Shebalin et al. (1974). The *ad-hoc* rules that emerged are shown in Table 2, and they have been used to convert the intensities from the manuscript (D) to EMS. We estimate the average conversion uncertainty to be about 0.5 EMS.

Table 2. Ad-hoc conversion rule between unknown intensity scale I_{ms} used in the manuscript from the Institute of Seismology in Belgrade (IoS-BEO, 1922a) and the EMS scale (I_{EMS}).

I_{ms}	VIII$^+$, VIII	VII$^+$, VII	VI	V	IV
I_{EMS} (EMS)	VII	VI–VII	V–VI	IV–V	IV

Analysing data from all sources listed above, the total number of estimated intensities is 278, of which 261 are related to intensities $I \geq$ III EMS. The breakdown according to the source is: A (questionnaires) – 127; B (newspapers, reports, ...) – 31; C (digitized intensity map) – 30; D and E (IoS-BEO, 1922a,b) – 90. Spatial distribution of observed intensities from Croatia, Serbia, Hungary and Bosnia and Herzegovina is shown in Fig. 4.

The earthquake was widely felt – our westernmost IDP (I = IV EMS) is about 220 km away, and Gilić (1923) reports that it was felt also in Zagreb. To the east

and southeast in Serbia there are reports of felt shaking up to about 180 km away. A selection of reports in contemporary newspapers and bulletins, or by eye-witnesses, may give us an idea of shaking effects at various distances:

– In *Osijek* (I = VI–VII EMS), which lies about 22 km to the SSW from the epicentre "...the earthquake first appeared as a vertical and then a horizontal wavelike movement lasting from 6 to 10 seconds. Many chimneys were destroyed, and buildings were damaged. Most of the population fled their homes, especially in the quarters of Upper Town and Retfala. Before that, a loud rumble was felt, like that of a heavy truck rushing by like a whirlwind." (Gilić, 1923). "It was felt much more strongly on the Drava river than in the city. The Drava became agitated, and the barges in front of the Regimental Garden, tied to one another, rocked so violently and struck each other so hard that the command was completely convinced the front barges had broken loose and were crashing into the ones behind." (*Hrvatski list*, 25 Nov. 1922). The *Bácsmegyei Napló* (25 Nov. 1922) reports that "...the startled people rushed outside, but the earthquake caused no fatalities or significant building damage, although a few house decorations fell off and bricks dropped from walls." *Zastava* (29 Nov. 1922) informed the readers that the telephone was out of order until 9 a.m.

– In *Sombor* (Serbia, D = 25 km, I = VI EMS) "...several buildings suffered cracks, and three chimneys collapsed on the main street. Fortunately, no casualties were reported." (*Bácsmegyei Napló*, 25 Nov. 1922)

– *Sotin* (D = 54 km, I = VI EMS): "The earthquake seemed to consist of two phases and lasted for about 10 to 15 seconds. There was a rumbling sound and jolts coming from below. Many people felt it, and many woke up. It was quite strong. Windows rattled, glasses and bottles shook, furniture was trembling, and objects hanging from the ceiling were swinging. Pictures and mirrors on the walls moved, and wooden beams – or even entire wooden houses – creaked. People ran out of their homes. A few chimneys or walls collapsed (eye-witness, from the questionnaire).

– A correspondent from Budapest reports to the *Prágai Magyar Hirlap* newspaper (25 Nov. 1922), that "...the earthquake in *Pécs* (Hungary, D = 58 km, I = V–VI EMS) on Thursday morning did not cause any major damage. People were awakened from their sleep and rushed out of their houses. Doors slammed shut, pictures fell off the walls, and window panes shattered.".

– In *Szeged* (Hungary, D = 117 km, I = V EMS) "...after three o'clock, an earthquake lasting a few moments shook the city. Many felt the ground tremble, the furniture creaked, and the chandelier hanging from the ceiling began to sway noticeably. In some places, pendulum clocks even stopped as a result of the earthquake." (*Szegedi Friss Hirek*, 25 Nov. 1922).

3.2. Inversion for the focal parameters

The result of applying the method discussed above to the 1922 earthquake intensity data is shown in Fig. 4. Only IDPs with the observed intensity larger than III EMS and within 150 km from the epicentre were used, which reduced the number of IDPs to $N = 249$.

The macroseismic epicentre is located farther north than any previously reported locations and farther east than most of them (compare Tables 1 and 3). The estimated macroseismic depth and epicentral intensity fall within the ranges published in earlier studies (Table 1). Confidence intervals at the 1σ-level (p =68%) are shown in parentheses for each inverted parameter in Table 3. Matrix plots of sampled parameter values from the Monte Carlo inversion stage (Fig. 5) allow estimation of confidence intervals at other confidence levels.

By approximating the standard errors (σ) as the half-widths of the corresponding 68% confidence intervals, we find that uncertainties in epicentral coordinates ($\sigma_\varphi = 0.071° = 7.9$ km, $\sigma_\lambda = 0.040° = 3.1$ km) are lower by a factor between 2.5 and 7 than those reported previously (see Table 1). The standard error

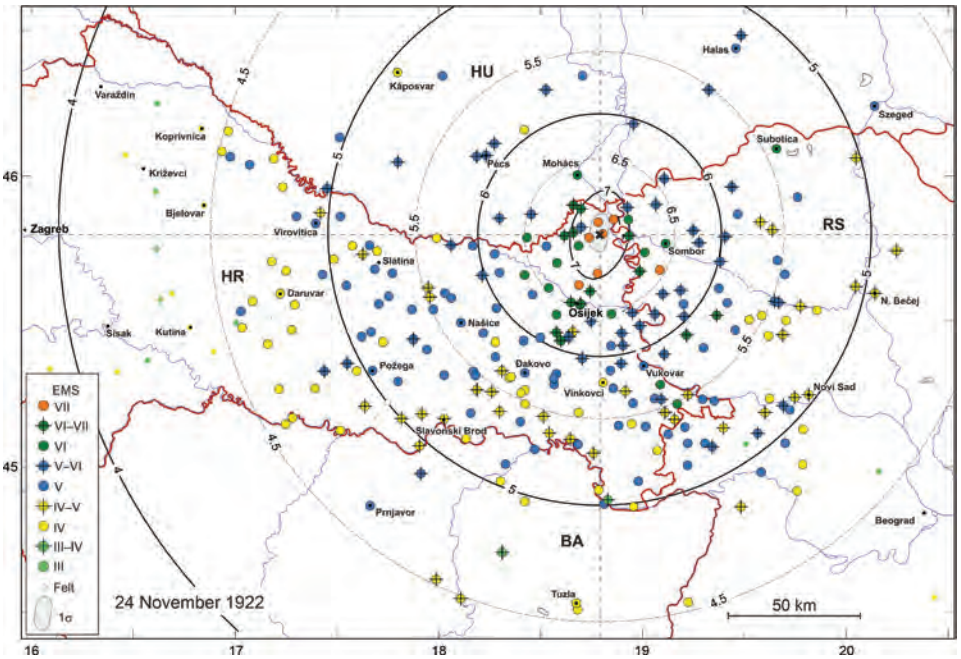


Figure 4. Estimated intensities for the earthquake of 24 November 1922. IDPs shown with small, pale circles were not used in the inversion ($I_{obs,i} \leq$ III EMS or $d_i > 150$ km). Theoretical isoseismals according to the KJE model with final inverted parameters (Table 3) are also shown. The 68%--confidence region for the epicentre is shown as a grey area around the epicentre (black cross). See caption to Fig. 1 for country abbreviations.

in depth (σ_h = 10.6 km) is somewhat larger than those in latitude and longitude, which is expected even for modern earthquakes. The standard error for epicentral intensity (σ_{I_0} = 0.5 EMS) is equal to the intensity discretization interval.

The uncertainties in depth and epicentral intensity arise in large part from a pronounced trade-off between h and I_0, clearly visible in the corresponding subplots in Fig. 5.

Most parameter pairs exhibit weak or no correlation. Beside the pair (h, I_0), notable exceptions include the pairs (h, k) with depth increasing with k, and (α, k), which is expected since both parameters describe intensity attenuation and are even combined into a single factor in the last term of eqs. (1) and (2). It is noteworthy that the minimum is clear and unambiguous for all inverted parameters (Fig. 5, bottom row).

Fig. 4 also displays the theoretical isoseismals corresponding to the best fitting model parameters describing the earthquake source and the intensity attenuation (see Table 3). The ellipticity (ε) and strike of the innermost isoseismals' long axis (γ) may indicate anisotropy in near-source attenuation or finite-source effects. These features may also be caused by favourable geometry of the available IDPs. They may also, in part, reflect trade-offs between inverted parameters. However, this does not appear to be the case here: the matrix plot in Fig. 5 shows no apparent correlation between either γ or ε and any of the other model parameters.

Table 3. Inverted parameters for the earthquake of 24 November 1922. Values in parentheses define 1σ confidence limits. $M_{Lm,5}$ and $M_{Lm,6}$ are local macroseismic magnitudes based on the equivalent radii of the 5th and 6th theoretical isoseismal (Herak et al., 2021a). The magnitudes are defined in section 3.3.

T = 02:15:46.4 ± 1.2 s UTC	$M_{Lm,5}$ = 5.6
φ = 45.798° N (45.730–45.872)	$M_{Lm,6}$ = 5.4
λ = 18.788° E (18.747–18.828)	$M_{Lm,\mathrm{a}}$ = 5.4
h = 11.2 km (2.0–19.2)	$M_{Lm,\mathrm{b}}$ = 5.1
I_0 = 7.2 EMS (6.7–7.7)	$M_{Lm,\mathrm{med}}$ = 5.4
ε = 2.3 (1.0–2.5)	M_{wm} = 5.3
γ = 13° ((–38) –(+35))	
α = 0.0021 km^{-1} (0.0002–0.0038)	$M_{LH,\mathrm{ZAG}}$ = 5.4
k = 2.6 (2.0–3.2)	$M_{LH,\mathrm{VIE}}$ = 5.6
σ = 0.499 EMS, N = 249	$M_{LH,\mathrm{med}}$ = 5.5

The fit of the average macroseismic field to the data is reasonably good, as the standard error of the fit is equal to the intensity discretization threshold (0.5 EMS). As noted above, the intensities are estimated according to five different

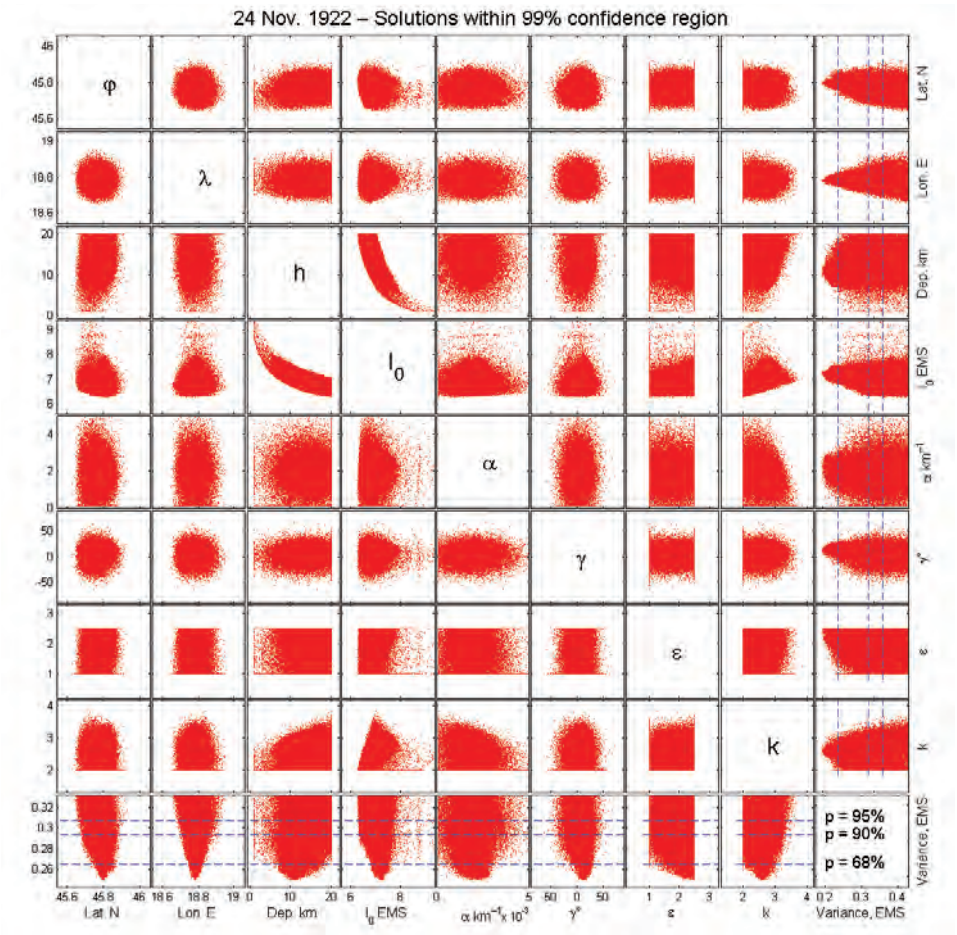


Figure 5. Matrix plot of variances for the eight inverted parameters through grid search and Monte Carlo sampling, falling below the 99%-confidence limit. The confidence levels of 95%, 90% and 68% are shown by blue dashed lines in right-most cell of the bottom row.

sources, some of which were converted from the unknown intensity scale (D and E in section 3.1 above), which may raise the question of the data homogeneity. It is therefore interesting to compare the distribution of residuals categorized by the data source, as given in Fig. 6.

The mean residuals of all dataset groups are very close to zero, and distributions are reasonably symmetric and follow the normal distribution. In particular, the group D+E does not stand out, thus indicating that our *ad-hoc* conversion rule (Table 2) from unknown intensity scale used in the manuscript from the Belgrade Institute of Seismology (IoS-BEO, 1922a) to EMS produced reasonable results.

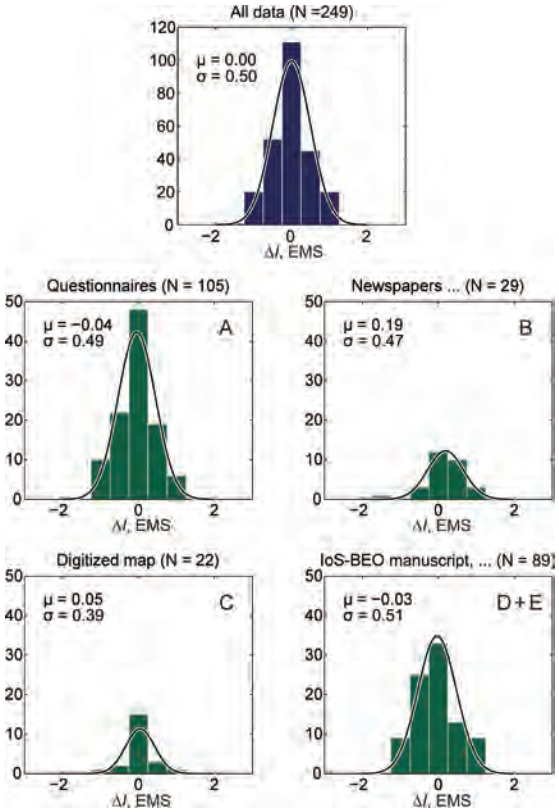


Figure 6. Histograms of intensity residuals ΔI (EMS) for all IDPs (top, blue), and for the four groups of data sources A–E (green, see section 3.1). Classes are 0.5 EMS wide.

3.3. Magnitudes and origin time

Local macroseismic magnitudes (M_{Lm}) were estimated using two approaches: from the mean radii of the fitted isoseismals 5.0 and 6.0 (denoted as $M_{Lm,5}$ and $M_{Lm,6}$), based on empirical relationships developed by Herak et al. (2021a) for north-western Croatia; and from two additional empirical formulas relating M_{Lm} to source depth (h) and epicentral intensity (I_0), proposed by Herak, D. (1995; $M_{Lm,a}$) and Herak, M. (1989; $M_{Lm,b}$), respectively:

$$M_{Lm,5} = 1.938 \log(R_5) + 1.675$$
$$M_{Lm,6} = 1.835 \log(R_6) + 2.345$$
$$M_{Lm,a} = 0.721\, I_0 + 1.283 \log(h) - 1.13$$
$$M_{Lm,b} = 0.88\, I_0 + 1.85 \log(h) - 3.18,$$

where R_5 and R_6 are radii of the circles having the same areas as the isoseismals 5.0 and 6.0, respectively (Herak et al., 2021a). The four magnitudes defined above

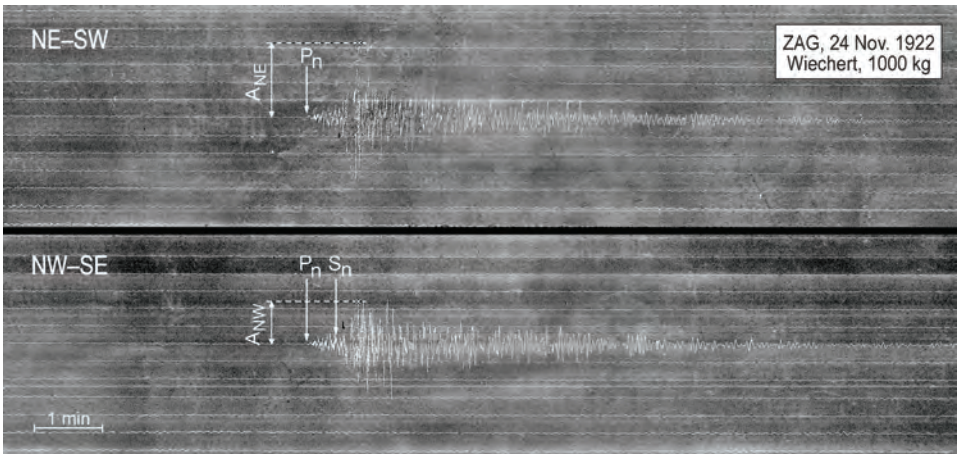


Figure 7. Seismograms of the earthquake of 24 November 1922 recorded by the horizontal Wiechert seismograph in Zagreb (1000 kg pendulum). The components are rotated by 45° relative to the standard setup.

range between 5.1 and 5.6 and are shown in Table 3, along with their median, $M_{Lm,\mathrm{med}} = 5.4$. As M_{Lm} is calibrated against the Croatian M_L, we may use the M_L–M_w conversion formula valid in Croatia (Herak, 2020) to estimate macroseismic moment magnitude $M_{wm} = 5.3$.

The 1922 earthquake was recorded by several European seismographs, as reported *e.g.* in bulletins from Belgrade for stations Belgrade, Mostar, Sarajevo and Sinj, from Vienna (VIE), or from Strasbourg for stations Strasbourg and Besançon. The seismograph in Zagreb (ZAG) was officially not working due to reconstruction (there are no bulletin data for 1922 after August), but seismograms recorded by the Wiechert horizontal seismograph (1000 kg) do exist in the archives, as well as the instrument calibration data and time corrections! Herewith we use the ZAG seismogram to estimate the instrumental magnitude (Fig. 7).

The horizontal components in Zagreb were rotated by 45° relative to the standard setup, so they recorded motions in the NW–SE and NE–SW directions. The calibration log-book shows that static magnification was $V_{\mathrm{NE}} = 219$ and $V_{\mathrm{NW}} = 220$, with the free periods equal to $T_0 = 10.3$ s, and damping ratios $\delta = 5.8$. The amplitudes on the two components corresponding to the maximum of the (A/T) ratio were $A_{\mathrm{NE}} = 22$ mm and $A_{\mathrm{NW}} = 13$ mm. The ground-motion period corresponding to these amplitudes was difficult to estimate due to rather slow recording paper speed of only 20 mm/min. By counting the number of zero-crossings on slightly retouched enlarged scans it is estimated as $T = 3.0$ s in both cases.

After taking amplification into account, and knowing the epicentral distance to Zagreb ($\Delta_{\mathrm{ZAG}} = 1.96°$), we could estimate the M_{LH} magnitude:

$$M_{LH,\mathrm{ZAG}} = \log(A_\mathrm{H}/T)_{\max} + 1.66\log(\Delta°) + 3.3 = 5.4,$$

where $A_H = \sqrt{A_{NE}^2 + A_{NW}^2}$.

According to the Vienna seismic bulletin for 1922, the station VIE reported ground amplitudes of $A_\mathrm{N} = 43$ μm, and $A_\mathrm{E} = (83)$ μm (probably indicating uncertain reading), and $T = 3$ s. With $\Delta = 2.99°$, we obtain $M_{LH,\mathrm{VIE}} = 5.6$. The median of ZAG and VIE estimates is $M_{LH,\mathrm{med}} = 5.5$, which is little higher than reported by Kárník (1969; $M_{LH} = 5.3$ based on 6 independent reports), and in very good agreement with $M_{Lm,\mathrm{med}} = 5.4$ obtained above.

Knowing the hypocentre and the onset-times of seismic phases the earthquake origin time may be determined. As mentioned above, at the time of the earthquake ZAG station was not in normal operation, and it seems that the clock-corrections were not taken very often. The closest ones we could identify were measured on 14 October 1922 ($\Delta t = -10.8$ s) and 17 December 1922 ($\Delta t = -2.3$ s), *i.e.* 39 days before and 23 days after the earthquake. Interpolating, we get $\Delta t = -5.7$ s on 24 November 1922. Adding this to the onset-times of Pn and Sn read from the ZAG seismograms (Fig. 7) we get t_Pn = 02:16:17.4 and t_Sn = 02:16:43.8. Subtracting the theoretical travel-times of the two phases according to the local model used to locate earthquakes in north Croatia we obtain the origin times $T_{\mathrm{H,ZAG}}$(Pn) = 02:15:45.3 UTC and $T_{\mathrm{H,ZAG}}$(Sn) = 02:15:47.6 UTC. Repeating the same procedure using the reported arrival time of Pn on the VIE station we get $T_{\mathrm{H,VIE}}$(Pn) = 02:15:46.2 UTC. Taking the average of the three estimates, we obtain T_H = 02:15:46.4 ± 1.2 s UTC.

3.4. Aftershocks

The strongest aftershock listed in various catalogues is reported to have occurred on 24 November 1922 at 02:28 UTC, just 13 minutes after the mainshock. It first appears in IoS-BEO (1922b), with a single intensity observation from Batina (VI, on the FM-M or MCS-M scale). Shebalin et al. (1974) list the event with $\varphi = 45.7$ N, $\lambda = 18.8$ E, $h = 26$ km, I_0 = V–VI MCS and $M = 4.8$, based on a single source (Milosavljević and Nedeljković, 1972). However, inspection of the Zagreb seismograms revealed no event around that time, although it should be clearly visible with the amplitude exceeding 4 mm. We therefore conclude that this event is either false or its magnitude has been significantly overestimated.

The manuscript IoS-BEO (1922a; source D, see section 3.1) reports four additional minor aftershocks with estimated maximum intensities ranging between III and V – likely on the FM-M scale – occurring through the end of November 1922. The CEC also notes a possible aftershock on 4 February 1923 at 22:55, with an intensity of I_0 = V (MCS scale), near the village of Suza.

Furthermore, thanks to detailed observations by the reformed priest K. Szigeti from the village of Vardarac (approximately 10 km NNE of Osijek), who carefully recorded the times of felt events, it is known that at least 23 weak aftershocks occurred by 3 January 1923 (*Bácsmegyei Napló*, 9 Jan. 1923).

4. Earthquake of 12 August 1924

Seismic activity in Baranja and near the Baranja–Bačka border persisted into 1924. For example, on 27 March 1924 at 14:10, an earthquake with a maximum intensity of IV MCS occurred near Batina (after CEC, Fig. 3). The strongest event took place on 12 August at 16:27, with epicentres from various catalogues distributed along a narrow, east–west trending strip approximately 25 km long (Table 1). This earthquake was felt across north-eastern Baranja, north-western Bačka, and the southern parts of the Hungarian counties of Baranya, Tolna, and Bács-Kiskun, at distances of up to 100 km.

The Belgrade Seismic Bulletin (IoS-BEO, 1924) reports intensity for seven localities in Baranja and Bačka, all assigned degree VI probably in MCS-M scale. In the introductory page of the Bulletin this scale is named 'International scale', and intensity degree VI is described simply as 'Strong'. It was converted here to V–VI EMS, according to the conversion table in Shebalin et al. (1974). All additional data were collected from contemporary newspapers. When data from both sources were available, we critically considered both pieces of information, allowing us to estimate intensities for 14 locations (Fig. 8).

The largest effects were reported from seven localities within a small area (15 km × 6 km) in Baranja and NW-most Bačka, with intensity up to VI–VII EMS in Batina, Zmajevac and Suza (Fig. 8). For instance:

– In *Zmajevac* (D = 1 km, I = VI–VII EMS) "...the tremor began with a strong rumbling and collapsed the chimneys of several houses. The earthquake repeated at 6:05 PM, 7:10 PM, 11:00 PM, and 2:07 AM. The terrified residents spent the night outdoors. .. In *Suza* (D = 4 km, I = VI–VII EMS) and *Batina* (D = 4 km, I = VI–VII EMS), the earthquake caused even greater damage, with chimneys and walls collapsing, and in several places, the roofs of houses also caved in." (*Miskolczi Napló*, 20 Aug. 1924).
– In *Mohács* (Hungary, D = 24 km, I = V EMS) the earthquake "... caused considerable excitement, as everyone felt its effect. The hanging lamps swung violently from their positions, and plates and glassware rattled and clinked together. However, there was no damage to buildings or other structures, except for the chimney of pharmacist Vilmos Auber's multi-story house, which partially collapsed." (*Dunavidék*, 17 Aug. 1924).
– In *Subotica* (Serbia, D = 72 km, I = IV–V EMS) "The tremors were particularly strong in older buildings. ... two quick, consecutive tremors were felt, accompanied by a dull rumbling sound. The two tremors lasted for 14 seconds. The windows rattled, and the furniture began to move. Most people walking on the street did not notice anything, but many residents rushed out of their apartments in fear." (*Bácsmegyei Napló*, 13 Aug. 1923).

– "Pictures tilted on the walls, chandeliers clinked together, and in one place, a flower vase on a table fell over." in *Pécs* (Hungary, D = 55 km, I = III–IV EMS) (*Pécsi Lapok*, 13 Aug. 1924).
– "In *Kanjiža* (Serbia, D = 99 km, I = IV EMS) the earthquake occurred at 5:30 PM and stopped after two tremors. The tremors shook doors, windows, and hanging lamps." (*Miskolczi Napló*, 20 Aug. 1924).

Given the limited number of IDPs, and since α and k characterize intensity attenuation at the regional scale, we fixed these parameters to the values derived for the 1922 earthquake (Table 3, Section 3.2) and inverted only for the remaining six parameters. The inversion results are presented in Table 4. The overall fit of the macroseismic field to the data is very good, with a low standard error of σ = 0.33 EMS. The macroseismic hypocentre is determined close to Zmajevac, with standard errors of coordinates: σ_φ = 0.062° = 6.8 km, σ_λ = 0.048° = 3.7 km, and σ_h = 6.1 km. The innermost isoseismals (5.5 and 6.0 EMS) are modelled as striking roughly SW–NE, with rather pronounced ellipticity.

Table 4. Inverted parameters for the earthquake of 12 August 1924. The magnitudes are defined in section 3.3. Values in parentheses define 1σ confidence limits.

φ = 45.807° N (45.732–45.855)	$M_{Lm,5}$ = 4.8
λ = 18.814° E (18.770–18.865)	$M_{Lm,6}$ = 4.4
h = 7.7 km (2.0–10.2)	$M_{Lm,a}$ = 4.7
I_0 = 6.5 EMS (6.3–8.0)	$M_{Lm,b}$ = 4.2
ε = 2.3 (1.0–2.5)	$M_{Lm,med}$ = 4.5
γ = 30° ((–30) –(+49))	M_{wm} = 4.4
α = 0.0021 km–1 (fix)	
k = 2.6 (fix)	
σ = 0.33 EMS, N = 14	

The macroseismic magnitude $M_{Lm,\mathrm{med}}$ = 4.5 is estimated in the same way as above (section 3.3). M_L-to-M_w conversion formula (Herak, 2020) then yields macroseismic moment magnitude M_{wm} = 4.4.

4.1. Foreshock and aftershocks

As noted above, a possible foreshock was recorded in the catalogues on 27 March 1924, *i.e.* four and half months before the mainshock (but see section 5.2 below!). The IoS-BEO (1924) lists 11 aftershocks in the first two days, mostly in the same location between Zmajevac, Batina, and Suza and with intensities between III and IV MCS-M(?), and one on 16 September 1924 with intensity of V MCS-M(?) reported from Bezdan, Batina, Kotlina and Bački Monoštor.

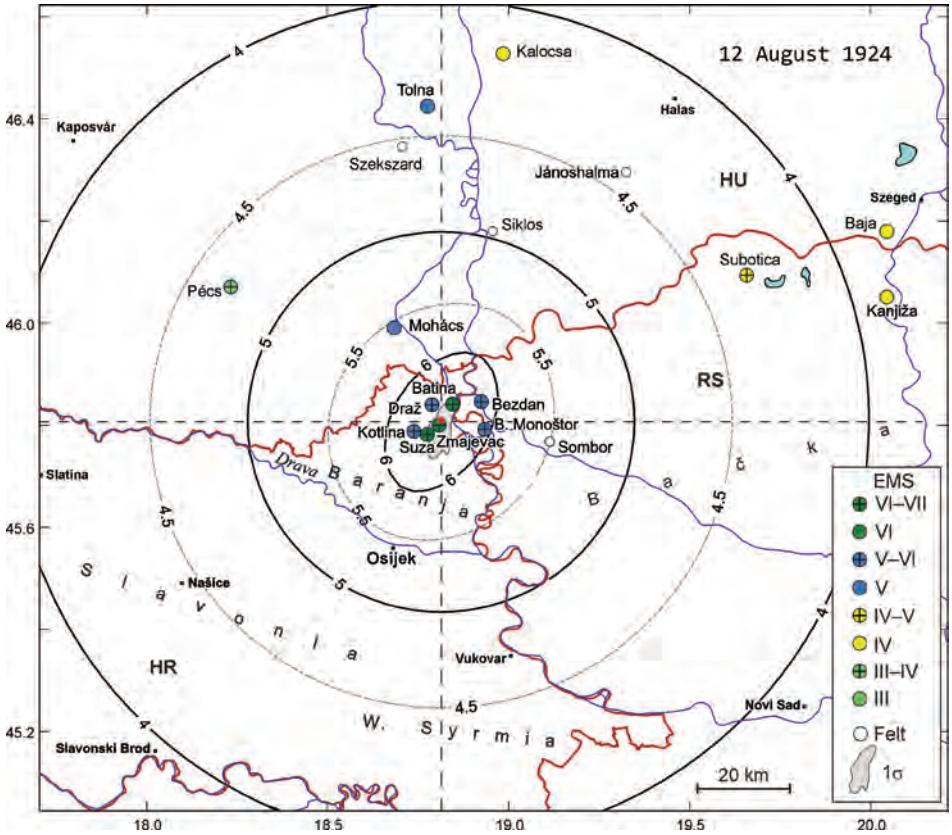


Figure 8. Estimated intensities for the earthquake of 12 August 1924. Theoretical isoseismals according to the KJE model and final model parameters (Table 4) are also shown. The 68%-confidence region for the epicentre is shown as grey area around the epicentre (small red cross). See caption to Fig. 1 for country abbreviations.

5. Discussion

5.1. The source

Macroseismic analyses of the two studied earthquakes yielded source locations that are very close to each other – the epicentres are only 2 km apart, well within each other's confidence regions (Fig. 9). This was not expected based on locations from various catalogues and studies so far (Table 1) in which the 1922 event is systematically located to the south and between 16 and 40 km from the one of 1924.

The foci of the two studied events as obtained here are within the Bansko Brdo tectonic unit (B in Fig. 9; Pikija et al., 1991b). Based on the spatial distribution of gravimetry anomalies, the neighbourhood of Bansko Brdo hills is singled

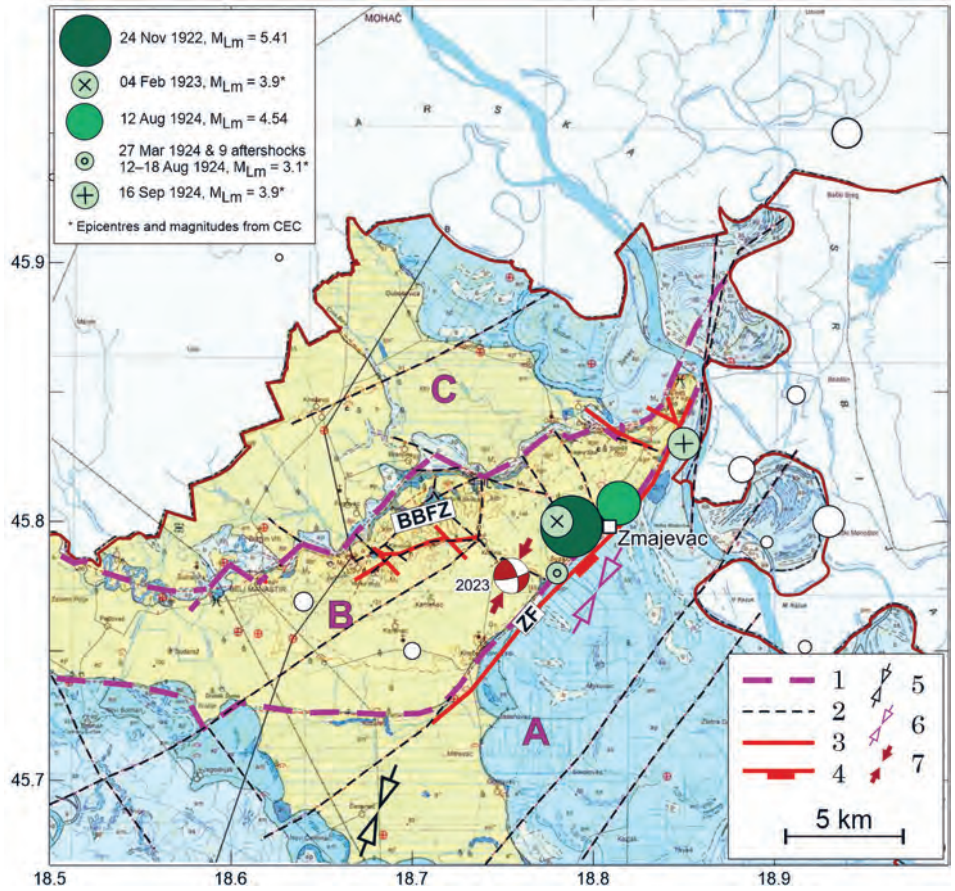


Figure 9. Earthquake epicentres (1876–2023) in Baranja including locations of the earthquakes of 1922 and 1924 as revised here. Circles in shades of green indicate events in the period 1922–1924 (see the legend in the top left corner). BBFZ – Bansko Brdo fault zone, ZF – Zmajevac fault. Tectonic units: A – Drava depression, B – Bansko Brdo, C – Northern Baranja–Bačka (after Pikija et al., 1991b). 1 – Boundaries of tectonic units, 2 – Inferred fault of unknown character (Pikija et al., 1991a), 3 – Confirmed fault of unknown character (HGI, 2009), 4 – Normal fault, covered (HGI, 2009). Maximum horizontal stress (S_{Hmax}) direction in the area after: 5 – Herak (2024), 6 – Békési et al. (2023). 7 – P-axis strike of the focal mechanism solution for the earthquake of 5 January 2023. Basemap is the Basic Geological Map 1 : 100000 (Pikija et al., 1991a). Shades of yellow – Pleistocene (mostly loess), shades of blue – mostly Holocene (alluvial deposits).

out by Prelogović and Cvijanović (1983) as the tectonically most active part of Baranja. Pikija et al. (1991b) also point out that investigations during geological mapping in the Bansko Brdo area to the NE of the epicentre of the 1922 event revealed possible faultings with displacements of the order of meters.

The epicentres of the 1922 and 1924 earthquakes are close to the boundary with the Drava depression tectonic unit (A in Fig. 9), which is mapped as a nor-

mal fault (named here as Zmajevac fault, ZF in Fig. 9). This fault strikes SW–NE, parallel to the contemporary orientation of the maximum horizontal stress (S_{Hmax}) in this area (*e.g.* Herak, 2024; Békési et al., 2023; Fig. 9). Under such a stress field, activation of the Zmajevac fault is not possible; therefore, it can be ruled out as a potential source of the studied earthquakes.

The only remaining candidate among the confirmed faults, based on the geological map of HGI (2009), is the Bansko Brdo fault zone (BBFZ in Fig. 9), located approximately 4 km from the epicentre of the 1922 earthquake. The detailed geometry and kinematic characteristics of these faults remain unknown. It is worth noting that the longest segment within the BBFZ trends approximately west–east, placing it in a favourable orientation to accommodate left-lateral strike-slip motion under the current stress field. The only focal mechanism solution obtained in the Baranja region to date – for the earthquake of 5 January 2023 (Fig. 9) – indeed features a sub-vertical, W–E striking nodal plane with prevalent sinistral strike-slip displacement. Given the uncertainties in the hypocentral locations of the 1922 and 1924 events (Figs. 4, 5 and 8), along with confirmed tectonic activity of the BBFZ and the very limited knowledge constraining its depth geometry and spatial extent, we consider this fault zone to be the most plausible source of the two studied earthquakes.

5.2. Independent events?

Given the significantly different catalogued locations (Table 1) and the 627-day interval between the 1922 and 1924 earthquakes, seismicity analyses have generally treated them as independent events. Indeed, most declustering algorithms will find the interevent time too long to consider the M_{wm} = 4.4 event as an aftershock of the mainshock (M_{wm} = 5.3). However, recent experience from Croatia with the mainshocks of similar magnitude in Zagreb on 22 March 2020 (M_w = 5.4, *e.g.* Herak et al., 2021b), or in Bosnia and Herzegovina near Berković on 22 April 2022 (M_w = 5.7, Dasović et al., 2024)[2] shows that over five or three years later, respectively, a significantly increased earthquake activity in the epicentral zones still persists. Considering also very low seismicity of Baranja, it seems improbable that the two strongest known events occurred independently about 21 months apart at the same place, so we propose that the event of 1924 is a late aftershock of the 1922 earthquake. If this is so, then also the earthquake of 27 March 1924 (section 4.1) should be considered an aftershock of the mainshock of 24 November 1922.

5.3. Intensity anisotropy

As seen in Figs. 4 and 8, the highest isoseismals were modelled as ellipses with the long axis striking between azimuths of γ = 13° and γ = 30°, albeit with

[2] At the time of writing of this paper, the latest aftershock with $M_L \geq 3.5$ occurred on 1 June 2025 (M_L 4.0), 1136 days after the mainshock of 22 April 2022.

rather large confidence intervals (Tables 3 and 4). This feature of the inversion algorithm is introduced to enable modelling of the near-source effects (*e.g.* finite source or rupture directivity), in which case we expect ellipse elongation along the fault strike. This seems not to be the case here, as no faults with a similar strike (SSW–NNE) are likely to be activated under the present stress field (Fig. 9). Therefore, if the observed ellipticity is real (and it seems that data indeed require it, see Fig. 5), its cause must be sought elsewhere. Firstly, local amplification could have played a role, as the Pleistocene loess deposits prevalent in the epicentral area and to the south of Bansko Brdo (yellow in Fig. 9) may have different amplification properties than the much younger Holocene alluvial sediments to the east and west (blue in Fig. 9). Furthermore, a considerable difference in depth of the bedrock that is expected to be shallower under the loess deposits, especially in the Bansko Brdo unit (see the profile in Pikija et al., 1991a), could have caused the soil resonant frequencies to approach the buildings' frequencies and thus induce increased damage due to resonance effects. And finally, noting that the meizoseismal ellipse's long axes are oriented similarly as the S_{Hmax} (Fig. 9), the preferential opening of vertical cracks with their faces parallel to the stress direction can cause strong attenuation anisotropy that is consistent with our observations (*e.g.* Zheng, 2000; Zhu and Tsvankin, 2006; Chapman, 2009; Bao et al., 2012). Among other factors, it depends on the size of cracks, their density, and degree of fluid saturation. Detailed analyses of the observed anisotropy need dedicated investigations of soil amplification and resonance properties, and/or numerical modelling of crack induced anisotropy based on a large set of observations, which is beyond the scope of this study.

6. Conclusions

Wherever earthquakes occur infrequently, accurate seismicity modelling critically depends on the detailed knowledge of the largest known earthquakes, including their hypocentral locations, focal mechanisms, magnitudes, and characteristics of the macroseismic field. This certainly holds true for Baranja, where CEC records only 25 earthquakes regardless of magnitude, and the first known listed event occurred in 1876.

The two earthquakes studied here are by far the largest known events that occurred in Baranja, so we tried to macroseismically relocate their foci using new intensity data points from Bosnia and Herzegovina, Croatia, Hungary, and Serbia, and reassess their magnitudes.

The main conclusions are:

– The epicentres of earthquakes of 24 November 1922 (M_{wm} = 5.3) and 12 August 1924 (M_{wm} = 4.4), are both relocated close to the village of Zmajevac (Fig. 9). They lie in the Bansko Brdo tectonic unit, near its boundary with the Drava depression unit. Specifically, the epicentre of the 1922 event was

located 13 km to the NNE with respect to the location in CEC thus almost doubling its distance from the regional centre, the city of Osijek. Likewise, the revised epicentre of the 1924 event lies 22 km to the west with respect to the current CEC record.

– Revised magnitudes of the earthquake of 1922 (M_{Lm} = 5.4, M_{wm} = 5.3) are higher than previous estimates, whereas for the 1924 event they are lower (M_{Lm} = 4.5, M_{wm} = 4.4) than previously reported (see Table 1).
– Macroseismic focal depths of 11 km and 8 km for the 1922 and 1924 events, respectively, are considerably smaller than 18 km and 14 km as quoted in CEC.
– The revised catalogue for the earthquakes in Baranja suggests that the Bansko Brdo tectonic unit is currently most likely to host significant earthquakes. In particular, no evidence remains that a strong earthquake ever occurred in the Drava depression or in the Northern Baranja–Bačka tectonic units. This finding could have serious impact on the seismic hazard estimation of Baranja and the nearby regions, reducing hazard in the south of Baranja, while notably increasing it in the neighbourhood of the Bansko Brdo hills.
– As there was no visible trace on the ZAG seismogram of the catalogued large aftershock 13 minutes after the mainshock (24 November 1922 at 02:28 UTC), we suggest removing it from the catalogues.
– We also suggest to treat the two studied earthquakes as dependent events, with 1924 a late aftershock of the 1922 mainshock.

Acknowledgments – We thank Iva Vrkić Seidl for help in acquiring historical data and relevant publications. We also thank Prof. Bruno Tomljenović for his help and discussions. Three constructive anonymous reviews helped us to improve the original manuscript.

References

Bao, X., Sandvol, E., Chen, Y. J., Ni, J., Hearn, T. and Shen, Y. (2012): Azimuthal anisotropy of Lg attenuation in eastern Tibetan Plateau, *J. Geophys. Res.*, **117**, B10309, https://doi.org/10.1029/2012JB009255.

Békési, E., Porkoláb, K., Wesztergom, V. and Wéber, Z. (2023): Updated stress dataset of the Circum-Pannonian region: Implications for regional tectonics and geo-energy applications, *Tectonophysics*, **856**, 229860, https://doi.org/10.1016/j.tecto.2023.229860.

Bianco, F., Del Pezzo, E., Castellano, M., Ibanez, J. and Di Luccio, F. (2002): Separation of intrinsic and scattering seismic attenuation in the southern Apennine zone, Italy. *Geophys. J. Int.*, **150**, 10–22, https://doi.org/10.1046/j.1365-246X.2002.01696.x.

Chapman, M. (2009): Modeling the effect of multiple sets of mesoscale fractures in porous rock on frequency-dependent anisotropy, *Geophysics*, **74**(6), D97–D103, https://doi.org/10.1190/1.3204779.

Cvijanović, D., Skoko, D. (1964): Potres u Dilj gori od 13. IV 1964. god., *Vijesti Hidrometeorološkog zavoda SR Hrvatske*, **14**, 31–33 (in Croatian).

Czecze, B., Győri, E., Timkó, M., Kiszely, M., Süle, B., and Wéber, Z. (2023): Seismicity of the Carpathian-Pannonian region: updated and revised earthquake database. *Földtani Közlöny*, **153**(4), 279–296 (in Hungarian with English abstract), https://doi.org/10.23928/foldt.kozl.2023.153.4.279.

Dasović, I., Herak, M., Herak, D., Latečki, H., Sečanj, M., Tomljenović, B., Cvijić- Amulić, S. and Stipčević, J. (2024): The Berkovići (BIH) M = 6.0 earthquake sequence of 22 April 2022 – seismological and seismotectonic analyses. *Tectonophysics*, **875**, 230253, https://doi.org/10.1016/j.tecto.2024.230253.

Gilić, A. (1923): Seizmička djelatnost u Hrvatskoj, Slavoniji i Međumurju godine 1922, *Rad Geofizičkog zavoda u Zagrebu*, **1**(1), 1–7 (in Croatian).

Gregl, M., Matasović, M. and Tvrtković, M. (2021): Kronologija potresa u Slavoniji između 1739. i 1835. godine (prema podacima iz zapisnika franjevačkih samostana u Brodu, Našicama, Osijeku, Vukovaru i Šarengradu), *Scrinia Slavonica*, **21**, 159–184, https://doi.org/10.22586/ss.21.1.10 (in Croatian with English summary).

Grünthal, G., Musson, R., Schwarz, J. and Stucchi, M. (1998): European Macroseismic Scale 1998, *Cahiers du Centre Européen de Géodynamique et de Séismologie*, **15**, European Center for Geodynamics and Seismology (Centre Européen de Géodynamique et de Séismologie), Luxembourg, 99 pp.

Herak, D. (1995): *Razdioba brzina prostornih valova potresa i seizmičnost šireg područja Dinare*, Ph. D. Thesis, University of Zagreb, Zagreb, 145 p. (in Croatian with English abstract).

Herak, M. (1989): The magnitude-intensity-focal depth relation for the earthquakes in the wider Dinara region. *Geofizika*, **6**, 13–21.

Herak, M. (2008): ModelHVSR - A Matlab Tool to Model Horizontal-to-Vertical Spectral Ratio of Ambient Noise. *Comput. Geosci.*, **34**(11), 1514–1526, https://doi.org/10.1016/j.cageo.2007.07.009.

Herak, M. (2020): Conversion between the local magnitude (M_L) and the moment magnitude (M_w) for earthquakes in the Croatian Earthquake Catalogue. *Geofizika*, **37**(2), 197–211, https://doi.org/10.15233/gfz.2020.37.10.

Herak, M. (2024): Croatian catalogue and database of focal mechanism solutions, characteristic mechanisms, and stress field properties in the Dinarides and the surrounding regions, *Geofizika*, **41**, 81–123, https://doi.org/10.15233/gfz.2024.41.5.

Herak, M. and Herak, D. (2024): Prošlo je stotinu godina od razdoblja najintenzivnije zabilježene potresne aktivnosti u Hrvatskoj i njezinoj neposrednoj okolici, Crtice iz povijesti, www.pmf.unizg.hr/geof/popularizacija_geofizike/crtice_iz_povijesti#1923-1925 (last visited 17 July 2025), Geofizički odsjek PMF-a, Zagreb, 11 pp (in Croatian).

Herak, M., Allegretti, I., Herak, D., Ivančić, I., Kuk, V., Marić, K., Markušić, S. and Sović, I., (2011): *Republika Hrvatska, Karta potresnih područja*, http://seizkarta.gfz.hr/hazmap/ (last visited 17 July 2025).

Herak, M., Herak, D. and Markušić, S. (1996): Revision of the earthquake catalogue and seismicity of Croatia, 1908-1992, *Terra Nova*, **8**, 86–94, https://doi.org/10.1111/j.1365-3121.1996.tb00728.x.

Herak, M., Herak, D. and Orlić, N. (2021b): Properties of the Zagreb 22 March 2020 earthquake sequence – analyses of the full year of aftershock recording. *Geofizika*, **38**(2), 93–116, https://doi.org/10.15233/gfz.2021.38.6.

Herak, M., Herak, D., and Živčić, M. (2021a): Which one of the three latest large earthquakes in Zagreb was the strongest – the 1905, 1906 or the 2020 one?, *Geofizika*, **38**(2), 117–146, https://doi.org/10.15233/gfz.2021.38.5.

HGI (2009): *Geološka karta Republike Hrvatske* M 1:300.000 (Geological map of the Republic of Croatia 1:300000), Hrvatski geološki institut (HGI), Zavod za geologiju, Zagreb.

Horvat, K. (1913): Zapisci od 1752.–1759. Ivana Josipovića, župnika Križevačkoga: prilozi za povijest hrvatsku u XVIII. vijeku iz "liber memorabilium" župe križevačke, priopćio Karlo pl. Horvat, *Starine*, **34**, 305–365 (in Croatian).

IoS-BEO (1922a): *Hand-written table with estimated macroseismic intensities for the earthquake of 24 November 1922*, Archives of the Department of Geophysics, Faculty of Science, University in Zagreb, Zagreb, 9 p. (in Serbian).

IoS-BEO (1922b): *Belgrade*, *Bulletin Sismique 1922,* Institute of Seismology, University of Belgrade, Belgrade, downloaded from: www.isc.ac.uk/printedStnBulletins/townpublist.php?townid=285, last visited 17 July 2025 (hand-written, in French).

IoS-BEO (1924): *Bulletin Sismique 1924*, Serie B, Macrosismes (Phénomène ressentis), Ed. J. Mihailović), l'Institut sismologique de l'Université de Beograd, Belgrade, 26 p., Downloaded from: www.isc.ac.uk/printedStnBulletins/townpublist.php?townid=285, last visited 17 July 2025 (in French).

Jánosi, I. (1907): Makroszeizmikus rengések feldolgozása a Cancaniféle egyenlet alapján, in *Az 1906 évi Magyarországi Földrengések*, A. Réthly and A. M. Kir (Editors), Orsz. Met. Föld. Int., Budapest, 77–82 (in Hugarian).

Josipović Batorek, S. (2013): Potres u Đakovštini 1964. godine, *Zbornik Muzeja Đakovštine*, 179–196 (in Croatian).

Kárník, V. (1969): *Seismicity of the European area*, Part 1, D. Reidel Publishing Company, Dordrecht, Holland, 364 pp.

Kišpatić, M., (1891): Potresi u Hrvatskoj (I dio), *Rad Jugoslavenske akademije znanosti i umjetnosti*, **107**, Zagreb, 81–164 (in Croatian).

Kövesligethy, R. D. (1906): A makroszeizmikus rengések feldolgozása, *Mathematikai és Természettudományi Értesítő*, **24**, 349–368 (in Hungarian).

Kövesligethy, R. D. (1907): Seismischer Stärkegrad und Intensität der Beben, *Gerlands Beitr. Geoph.*, **8**, 24 (in German).

Krčelić, B. A. (1952): *Annuae ili historija 1748–1767*, Jugoslavenska akademija znanosti i umjetnosti, 630 p. (in Croatian).

Lammers, S., Weatherill, G., Grünthal, G. and Cotton, F. (2023): *EMEC-2021 – The European*-Mediterranean *Earthquake Catalogue – Version 2021.* GFZ Data Services, https://doi.org/10.5880/GFZ.EMEC.2021.001.

Markušić, S., Gülerce, Z., Kuka, N., Duni, L., Ivančić, I., Radovanović, S., Glavatović, B., Milutinović, Z., Akkar, S., Kovačević, S., Mihaljević, J. and Šalić, R. (2016): An updated and unified earthquake catalogue for the Western Balkan Region. *B. Earthq. Eng.*, **14**, 321–343, https://doi.org/10.1007/s10518-015-9833-z.

Mayeda, K., Koyanagi, S., Hoshiba, M., Aki, K., and Zeng, Y. (1992): A comparative study of scattering, intrinsic, and coda Q^{-1} for Hawaii, long valley and central California between 1.5 and 15 Hz. *J. Geophys. Res.*, **97**, 6643–6659, https://doi.org/10.1029/91JB03094.

Mileta, A. (1966a): Potres u području Slavonskog Broda 13. IV. 1964. (part 1). *Građevinar*, **18**(3), 114–121 (in Croatian).

Mileta, A. (1966b): Potres u području Slavonskog Broda 13. IV. 1964. (part 2). *Građevinar*, **18**(5), 199–204 (in Croatian).

Milosavljević, R. and Nedeljković, S. (1972): *Earthquake catalogue. Yugoslavia – Serbia* (manuscript), Belgrade.

Musson, R. M. W. (2009): MEEP 2.0 User guide, *British Geol. Surv. Open-File Rept*. OR/09/045, 22.

Penzar, I. (1982): Zapisi o potresima u Slavoniji i Bačkoj iz 18. i 19. stoljeća, *Acta Seismologica Iugoslavica*, **8**, 49–55 (in Croatian with English abstract).

Pikija, M., Šikić, K., and Trifunović, S. (1991a): *Osnovna geološka karta 1:100 000, list Mohač L 34-74*, Hrvatski geološki institut, Zagreb, 2015, (in Croatian).

Pikija, M., Šikić, K., and Trifunović, S. (1991b): *Osnovna geološka karta 1:100 000, Tumač za list Mohač L 34-74*, Hrvatski geološki institut, Zagreb, 2015, 88 p. (in Croatian).

Pilar, Đ. (1886): Djakovački potres dne 24. ožujka 1884. *Rad Jugoslavenske akademije znanosti i umjetnosti*, **78**, 9–174 (in Croatian).

Prelogović, E. and Cvijanović, D. (1983): Prikaz: neotektonske aktivnosti dijela Slavonije, Baranje i Bačke, *Geol. vjesnik*, **36**, 241–254 (in Croatian with English abstract).

Schmid, S. M., Fügenschuh, B., Kounov, A., Maţenco, L., Nievergelt, P., Oberhänsli, R., Pleuger, J., Schefer, S., Schuster, R., Tomljenović, B., Ustaszewski, K. and van Hinsbergen, D. (2020): Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey. *Gondwana Research,* **78**, 308–374, https://doi.org/10.1016/j.gr.2019.07.005.

Shebalin, N. V. (Ed.) (1974): *Catalogue of Earthquakes (of the Balkan Region), Part III: Atlas of Isoseismal Maps*, UNDP/UNESCO Survey of the Seismicity of the Balkan Region, Skopje, Macedonia, 275 pp.

Shebalin, N. V., Kárnik, V. and Hadžievski, D. (Eds.) (1974): *Catalogue of Earthquakes I–II*, UNDP/UNESCO Survey of the Seismicity of the Balkan Region, Skopje, Macedonia.

Shebalin, N. V., Leydecker, G., Mokrushina, N. G., Tatevossian, R. E., Erteleva, O. O. and Vassiliev, V. Yu. (1998): *Earthquake Catalogue for Central and Southeastern Europe 342 BC–1990 AD*, Final Report to Contract ETNU–CT93–0087, Bruxelles.

Stipčević, J., Tkalčić, H., Herak, M., Markušić, S. and Herak, D. (2011): Crustal and uppermost mantle structure beneath the External Dinarides, Croatia, determined from teleseismic receiver functions. *Geophys. J. Int.*, **185**(3), 1103–1119, https://doi.org/10.1111/j.1365-246X.2011.05004.x.

Zheng, Z. (2000): Seismic anisotropy due to stress-induced cracks, *International Journal of Rock Mechanics and Mining Sciences* **37**, 39–49, https://doi.org/10.1016/S1365-1609(99)00090-8.

Zhu, Y and Tsvankin, I. (2006): Plane-wave propagation in attenuative transversely isotropic media. *Geophysics*, **71**(2), T17–T30, https://doi.org/10.1190/1.2187792.

Zsíros, T. (2000): *A Kárpát-medence szeizmicitása és földrengésveszélyessége: Magyar földrengéskatalógus (456–1995)*, Hungarian Academy of Sciences, Institute of Geodesy and Geophysics, Budapest, Hungary, 482 p. (in Hungarian).

Consulted newspaper articles from *Arcanum** (https://www.arcanum.com/en/), *ANNO*$^{+}$ (https://anno.onb.ac.at/), *Pretraživa digitalna biblioteka*$^{\#}$ (https://pretraziva.rs), all last visited 18 July 2025, and other sources:

1922–1923

8 Órai Ujság, 25. Nov. 1922* – *A Nep,* 25 and 28 Nov. 1922* – *Alföldi Ujság,* August–December 1922 * – *Arbeiter Zeitung*, 25 Nov 1922^{+} – *Az Est,* 25 Nov. 1922* – *Bácsmegyei Napló*, 25 Nov. 1922 and 9 Jan. 1923* – *Bécsi Magyar Újság,* 25 Nov. 1922* – *Brassói Lapok,* 26 Nov. 1922* – *Budapesti Hirlap,* 26 Nov. 1922* – *Délmagyarország,* 25 and 29 Nov. 1922* – *Deutschösterreichische Tages-Zeitung*, 25 Nov 1922^{+} – *Dombóvári Hírlap,* 3 Dec. 1922* – *Dunántúl,* 25 and 29 Nov. 1922* – *Dunavidek,* 26 Nov. 1922* – *Egri Újság,* 25, 29, and 30 Nov. 1922* – *Ellenzék,* 26 Nov. 1922* – *Friss Hirek,* 28 and 29 Nov. 1922* – *Friss Ujsag,* 25 Nov. 1922* – *Hirado Pozsony*, 25 Nov. 1922* – *Hrvatski list*, 24 Nov. 1922 – *Jasz Nagykun Szolnokmegyei Lapok,* 30 Nov. 1922* – *Jovo Becs*, 25 and 26 Nov. 1922* – *Kassai Ujsag*, 26 Nov. 1922* – *Kecskeméti Közlöny*, 26 and 30 Nov. 1922* – *Kiskun-Halas Helyi Értesítője*, 20 Aug. 1924* – *Kleine Volks Zeitung*, 28 Nov 1922* – *Korosvidek*, 25 Nov. 1922* – *Kronen Zeitung*, 25 Nov 1922^{+} – *Linzer Volksblatt*, 26 and 29 Nov 1922^{+} – *Magyar Hirlap,* 25. Nov. 1922* – *Magyar Szo Eger*, 25 Nov. 1922* – *Magyarorszag*, 25 Nov. 1922* – *Mohacsi Hirlap*, 26 Nov. *1922** – *Nemzeti Ujsag*, 25 and 28 Nov. 1922* – *Nepszava*, 25 Nov. 1922* – *Neues Grazer Tagblatt*, 28 Nov 1922^{+} – *Neues Wiener Journal*, 25 and 28 Nov 1922^{+} – *Neues Wiener Tagblatt*, 28 Nov. 1922^{+} – *Nyirvidek*, 25 Nov, 1922* – *Pecsi Est*, 25, 26 and 29 Nov. 1922* – *Pecsi Lapok*, 25, 26, 29 and 30 Nov. 1922* – *Pesti Hirlap*, 25 and 28 Nov. 1922* – *Prágai Magyar Hirlap,* 26 Nov. 1922* – *Prager Tagblatt*, 26 Nov 1922^{+} – *Salzburger Tagblatt*, 25 and 29 Nov 1922^{+} – *Somogyi Ujsag,* 25 and 28 Nov. 1922* – *Sopronvarmegye*, 25 Nov. 1922* – *Szegedi Friss Hirek*, 25, 26, 28 and 29 Nov. 1922* – *Szegedi Friss Ujsag*, 29 Nov. 1922* – *Szozat*, 26 Nov. 1922* – *Tagblatt*, 26 Nov 1922^{+} – *Tages-Post*, 26 Nov 1922^{+} – *Tolnamegyei Ujsag*, 25 Nov.1922* – *Uj Barazda*, 25 and 28 Nov. 1922* – *Uj Kelet*, 25 Nov. 1922* – *Uj Nemzedek*, 25 and 29 Nov. 1922* – *Uj Somogy*, 25 and 28 Nov. 1922* – *Vasarhelyi Reggeli Ujsag*, 25 Nov. 1922* – *Virovitičan*, 24

Nov. 1922 – *Voralberger Tagblatt*, 29 Nov 1922^{+} – *Wiener Zeitung*, 28 Nov. 1922^{+} – *Zastava*, 25 and 29 Nov. 1922$^{\#}$.

1924

Aradi Közlöny, 15 Aug. 1924* – Az Ujság, 13 Aug. 1924* – *Bácsmegyei Napló*, 13, 24, and 30 Aug. 1924* – Budapesti Hírlap, 13 Aug. 1924* – Délmagyarország, 13 Aug. 1924* – Dunántúl, 13 Aug. 1924* – *Dunavidék*, 17 Aug. 1924* – *Egyetértés,* 13 Aug. 1924* – Friss Ujság, 13 Aug. 1924* – *Karcagi Hirlap*, 16 Aug. 1924* – *Kärntner Tagblatt,* 17. Aug 1924^{+} – *Kecskeméti Közlöny*, 14 Aug. 1924* – Kecskeméti Lapok, 14 Aug. 1924* – *Kiskun-Halas Helyi Értesítője*, 20 Aug. 1924* – *Magyarság*, 13 Aug. 1924* – *Miskolczi Napló*, 15 and 20 Aug. 1924* – *Mohacsi Hirlap*, 17 Aug. 1924* – *Morgenzeitung*, 13 Aug. 1924^{+} – *Nemzeti Ujsag,* 13 Aug. 1924* – *Neues Grazer Tagblatt*,15 Aug 1924^{+} – *Pécsi Lapok*, 13 Aug. 1924* – *Pester Lloyd*, 13 Aug 1924^{+} – *Pesti Naplo*, 13 Aug. 1924* – *Politika*, 14 Aug. 1924 – Reggeli Hirlap, 13 Aug. 1924* – *Reichspost,* 14 Aug. 1924^{+} – *Somogyi Ujsag*, 14 Aug. 1924* – *Sopronvármegye*, 13 Aug. 1924* – *Szeged,* 13 Aug. 1924* – Szegedi Uj Nemzedék, 13 Aug. 1924* – Szózat, 13 Aug. 1924* – *Tolnamegyei Ujság*, 16 Aug. 1924* – Uj Előre, 13 Aug. 1924* – *Uj Nemzedek*, 14 Aug. 1924* – *Uj Somogy*, 14 Aug. 1924* – *Vásárhelyi Napló,* 28. Aug. 1924* – *Világ,* 13 Aug. 1924* – *Vreme*, 14, and 16 Aug. 1924$^{\#}$ – *Wiener Morgenzeitung*, 13 Aug. 1924^{+} – *Wiener Zeitung*, 13 Aug 1924^{+} – *Zalai Közlöny*, 13 Aug. 1924*.

Appendix – Modelling elliptical anisotropy of the macroseismic near field

As noted in section 2 in the main text, the anisotropy is modelled by reducing epicentral distance d according to the assumed elliptical anisotropy of the macroseismic field. The theoretical intensity at i-th intensity data point (IDP) is then computed using the reduced distance D_i instead of the true epicentral distance d_i:

$$I_i = I_0 - k \log(R_i/h) - k\,\mu\,\alpha(R_i - h),$$
$$R_i = (D_i^2 + h^2)^{1/2}, \quad D_i = d_i / c(\phi_i, \gamma, \varepsilon, d_{\mathrm{el}}),$$

[equations (2a) and (2b) again]. Here c_i is the correction factor depending on four parameters – ϕ_i (azimuth of i-th IDP with respect to the epicentre), γ (strike of the ellipse long axis), ε (ellipticity of the isoseismal at the epicentre), and d_{el} (the distance after which the medium is considered isotropic). The procedure is shown in Fig. A1.

For given values of γ, ε, and d_{el} the isoseismal shape is an ellipse with the parameters (γ, ε) centred at the epicentre with radii $E(\varphi)$ (Fig. A1a). Decrease of

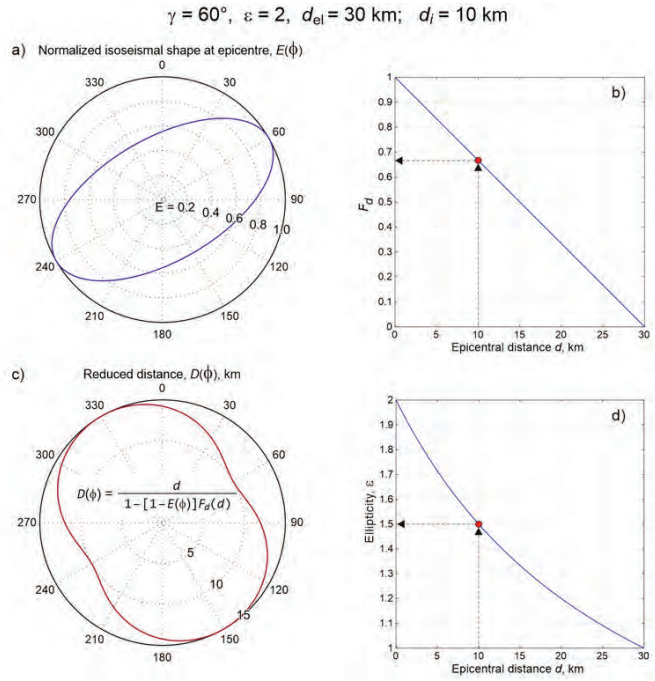


Figure A1. Illustration of the procedure to allow for elliptical anisotropy of the macroseismic near field defined by parameters as shown in the header of the figure, for the epicentral distance of d_i = 10 km.

anisotropy as a function of epicentral distance is controlled by the linear factor F_d (Fig. A1b):

$$F_{di} = 1 - d_i/d_{\mathrm{el}} \qquad \text{for } d_i \le d_{\mathrm{el}}$$

$$F_{di} = 0 \qquad \text{for } d_i > d_{\mathrm{el}}.$$

Then, c_i is defined as:

$$c_i = [1 - (1 - E(\phi_i))\, F_{di}],$$

and $D(\varphi) = d/c$ (Fig. A1c). As shown in Fig. A1d, the ellipticity ε is thus implicitly also modelled to decrease with distance, reaching $\varepsilon = 1.0$ for $d_i \ge d_{\mathrm{el}}$.

Electronic supplement

Files 1922-11-24-Baranja.IDP and 1924-08-12-Baranja.IDP containing coordinates of localities and estimated intensities (EMS-98 scale) for the two studied earthquakes.

SAŽETAK

Potresi u Baranji 1922. i 1924. godine

Marijan Herak i Davorka Herak

U područjima niske seizmičnosti, poput Baranje u sjeveroistočnoj Hrvatskoj, procjene seizmičke opasnosti uvelike ovise o detaljnoj karakterizaciji rijetkih, ali najjačih poznatih potresa. Ovo istraživanje usmjereno je na dva najsnažnija povijesna potresa u ovom području, koji su se dogodili 24. studenoga 1922. i 12. kolovoza 1924. Ponovno smo ih analizirali koristeći novoprikupljene makroseizmičke podatke iz Bosne i Hercegovine, Hrvatske, Mađarske i Srbije, pri čemu je broj opažanja intenziteta za potres iz 1922. povećan sa 106 na 278, dok je potres iz 1924., koji ranije nije bio makroseizmički analiziran, opisan na temelju 14 opažanja.

Korištenjem modificiranog Kövesligethy–Jánosi-eva modela koji u obzir uzima anizotropiju intenziteta u epicentralnom području provedena je inverzija makroseizmičkog polja radi relokacije epicentara te procjene žarišnih dubina i magnituda. Oba su makroseizmička epicentra locirana u neposrednoj blizini sela Zmajevac, unutar tektonske jedinice Bansko brdo, blizu njezine granice s Dravskom depresijom. Epicentar potresa iz 1922. pomaknut je 13 km prema sjeveroistoku u odnosu na izvornu lokaciju u Hrvatskom katalogu potresa (CEC), dok je epicentar potresa iz 1924. pomaknut 22 km prema zapadu. Revidirane momentne magnitude za potrese 1922. i 1924. iznose $M_{wm} = 5{,}3$ odnosno $M_{wm} = 4{,}4$. Procijenjene žarišne dubine pliće su od prethodno navedenih: 11 km i 8 km u odnosu na 18 km i 14 km u CEC-u.

Rezultati ukazuju da je značajna seizmičnost Baranje ograničena na tektonsku jedinicu Bansko brdo jer nema spoznaja o jakim potresima ili odgovarajućem seizmičkom

potencijalu postojećih rasjeda u Dravskoj depresiji ili u jedinici Sjeverna Baranja–Bačka. Ovo ima važne posljedice za procjenu seizmičke opasnosti u Baranji. Nadalje, nismo našli instrumentalne dokaze za katalogizirani najveći naknadni potres 13 minuta nakon glavnog potresa 1922. te predlažemo njegovo uklanjanje iz kataloga. Konačno, potres iz 1924. tumačimo kao kasni naknadni potres glavnog potresa iz 1922.

Ključne riječi: inverzija makroseizmičkog polja, seizmičnost Baranje, potresni izvori u Baranji, povijesni potresi, seizmički hazard

Corresponding author's address: Prof. emer. Marijan Herak, Department of Geophysics, Faculty of Science, University of Zagreb, Horvatovac 95, 10000 Zagreb, Croatia. email: mherak@gfz.hr.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.