

Seismic activity on the territory of Slovakia in 2021

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Abstract: The National Network of Seismic Stations of Slovakia (NNSS) consists of eight short period and six broadband permanent seismic stations and a data centre located at the Earth Science Institute of the Slovak Academy of Sciences (ESI SAS). The NNSS recorded and detected 10 656 seismic events from all epicentral distances in 2021. Totally 88 earthquakes originated in the territory of Slovakia in 2021. This paper provides basic information on the configuration of the NNSS, routine data processing, seismic activity on the territory of Slovakia in 2021 as well as macroseismic observations collected in 2021.

Key words: Slovakia, National Network of Seismic Stations, seismicity, macroseismic observations

1. Introduction

The seismic activity on the territory of Slovakia and adjacent areas has been reported on the daily basis by the so called Seismo Reports published on the web sites of the Department of Seismology, ESI SAS http://www.seismology.sk/Seismo_Reports/reports.html and in annual reports as a part of the project Partial monitoring system – Geological factors (*Liščák et al., 2022*, in preparation) which is solved with a contract between ESI SAS and State Geological Institute of Dionýz Štúr. The aim of this paper is to provide a quick overview of earthquakes which originated on the territory of Slovakia or were macroseismically felt on the territory of Slovakia in 2021.

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2. Seismic stations operating in 2021

The seismic monitoring of the Slovak territory is provided by the NNSS operated by the ESI SAS (*ESI SAS, 2004; Csicsay et al., 2018*), *Local Seismic Network in Eastern Slovakia* operated by the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava and local network of seismic stations around NPPs Jaslovské Bohunice and Mochovce operated by Progseis Ltd. company. The networks of seismic stations cooperate, and the exchange of data is on the regular basis. The positions of the seismic stations on the territory of Slovakia are shown in Fig. 1.

In 2021 the NNSS consisted of thirteen permanent seismic stations, from which six are short period and seven are broadband. The broadband stations are: Kolonické sedlo (KOLS), Izabela (IZAB), Liptovská Anna (LANS), Modra (MODS), Skalnaté pleso (SPC), Vyhne (VYHS) and Bratislava – Železná studnička (ZST). The short period stations are: Hurbanovo (HRB), Iža (SRO1), Kečovo (KECS), Moča (SRO2), Stebnícka Huta (STHS), Šrobárová (SRO). The HRB is the oldest NNSS seismic station that has been in operation since 1909 (*Pajdušák, 1997; Csicsay and Luby, 2021*). The broadband station Červenica (CRVS) located in Slanské Hills has been temporarily out of operation since 2018.

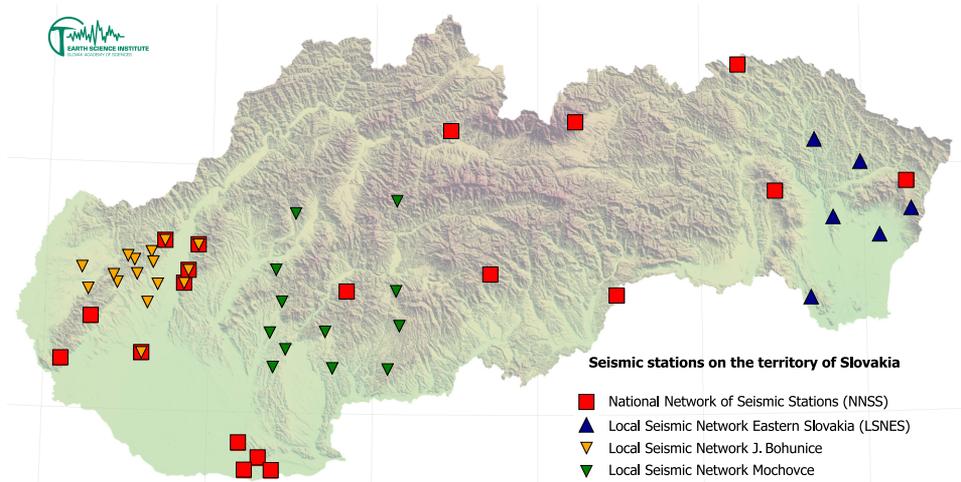


Fig. 1. Seismic stations operational on the territory of Slovakia in 2021.

At the Liptovská Anna (LANS) seismic station the original short period sensor LE3D and the SEMS collection system were replaced by the Metrozet MBB2 120s broadband seismometer and the more modern Wave32 data acquisition system on April 16, 2021. The NNSS permanent seismic stations and their instrumentation are summarized in Table 1. More details can be found on the web page <http://www.seismology.sk/NationalNetwork>.

Four additional short period seismic stations have been operated on the jointly bases of ESI SAS and other institutions. The seismic stations Banka (BAN), Jalšové (JAL), Podolie (POD) and Tematín (TEMA) located in the Little Carpathians and Považský Inovec Mts. have been operated in cooperation with Progseis Ltd. company and the Institute of Rock Structure and Mechanics of the Czech Academy of Sciences (IRSM CAS) (*Fojtíková et al., 2015*). These stations have been installed as temporary seismic stations.

Table 1. Equipment of seismic stations of the NNSS operating in 2021.

Station	ISC code	Lat. [°N]	Long. [°E]	Alt. [m]	Sensor	DAS	Sampl. freq.	Data format
Bratislava Žel. Studnička	ZST	48.196	17.102	250	3×SKD	Wave24	100/sec	mSEED
Vyhne	VYHS	48.493	18.836	450	STS-2	Wave24	100/sec	mSEED
Modra-Piesok	MODS	48.373	17.277	520	STS-2	Wave32	100/sec	mSEED
Hurbanovo	HRB	47.873	18.192	115	2× Mainka	Analog	–	smoked paper
Izabela	IZAB	48.569	19.713	450	Guralp- 40T-60s	Gaia	100/sec	mSEED
Iža	SRO1	47.7622	18.2328	111	LE3D	PCM	20/sec	mSEED
Kečovo	KECS	48.483	20.486	345	LE3D	Wave24	100/sec	mSEED
Kolonické sedlo	KOLS	48.933	22.273	460	Guralp- 6T-30s	Wave32	100/sec	mSEED
Liptovská Anna	LANS	49.151	19.468	710	Metrozet	Wave32	100/sec	mSEED
Moča	SRO2	47.763	18.394	109	Guralp- 40T-1s	Wave24	100/sec	mSEED
Stebnička Huta	STHS	49.417	21.244	534	LE3D	Wave24	100/sec	mSEED
Šrobárová	SRO	47.813	18.313	150	3× SKM-3	Wave24	100/sec	mSEED
Skalnaté Pleso	SPC	49.189	20.234	1751	Guralp- 40T-30s	SeisComp EarthData	100/sec	mSEED

3. Data processing

Digital data from all NNSS stations (except the analogue seismic station HRB) are transferred in real-time to the data centre at the ESI SAS either by the internet or satellite telemetry. Software package SeisComp3 (Weber et al., 2007) and SeedLink server are used for data acquisition and exchange.

Beside observations from the NNSS stations the data centre at ESI SAS also use the data from the above-mentioned local networks of seismic stations in Slovakia and observations from networks of neighbouring countries: Austrian Seismic Network (ZAMG – Zentralanstalt für Meteorologie und Geodynamik, 1987), Czech Regional Seismic Network (Institute of Geophysics, Academy of Sciences of the Czech Republic, 1973), Hungarian National Seismological Network (Kövesligethy Radó Seismological Observatory, 1992), Local seismological network for monitoring NPP Dukovany (Institute of Physics of the Earth Masaryk University, 2014), GEOFON Seismic Network (GEOFON Data Center, 1993), Polish Seismological Network. These stations form a so-called Regional Virtual Network of ESI SAS that consists of approximately 55 seismic stations.

Routine analysis of the digital recordings at the ESI SAS has been performed by the Unix package Seismic handler (Stammler, 1993). Interactive locations of seismic events within Seismic Handler are performed by external program LocSat. The collected digital observations are manually processed on the daily basis. The epicentre locations are based on the IASP91 travel-time curves. Local magnitudes have been determined from the maximum vertical trace amplitudes of Sg waves, using the pre-defined Seismic Handler formula for local events. Continuous raw seismic data from the NNSS are stored in a local archive and seismic data interpretations (together with information on equipment of stations) are stored in a web accessible database.

4. Seismic activity in 2021

The NNSS analysed 10 656 local, regional and teleseismic events in 2021. More than 40 000 seismic phases were determined. Seismic events identified as quarry blasts were excluded from further processing and were not included in the event statistics. All events recorded by the NNSS and analyses at the data centre at ESI SAS has been reported in the so called Seismo Reports and published on the above-mentioned web sites of the Department

of Seismology, ESI SAS.

Altogether 88 seismic events located by the NNSS originated on the territory of Slovakia in 2021 (Fig. 2). Known quarry blasts are not included in this number. 20 earthquakes reached local magnitude 1.0 or more and are listed in Table 2. The strongest earthquake occurred on January 28 at 8:16 UTC in Vtáčnik Mountains with local magnitude M_L 3.2.

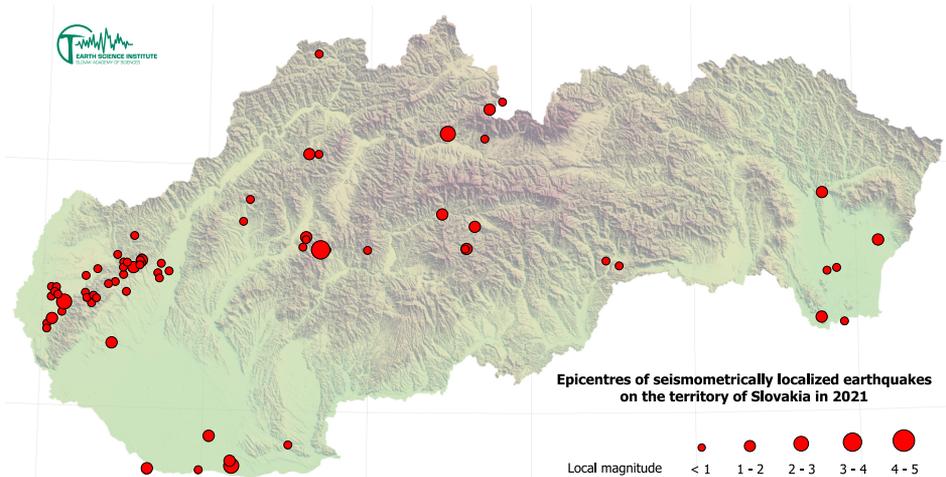


Fig. 2. Map of epicentres of local earthquakes originated on the territory of Slovakia in 2021. Diameters of the circles are proportional to local magnitudes.

The seismicity of the Slovak territory is dominated by the Little Carpathians and Komárno seismic source zones (Hók *et al.*, 2016). The strongest earthquake in the Little Carpathians source zone was detected on the June 19 at 18:04 UTC with local magnitude M_L 1.5. The strongest earthquake in the Komárno source zone was detected on the August 29 at 21:57 UTC with local magnitude M_L 2.0. Although the low level of seismic activity from the last decades remained unchanged also in 2021, these two source zones remain of the primary interest for the monitoring of seismic activity within the territory of Slovakia.

5. Macroseismic observations

Seven earthquakes were macroseismically felt on the territory of Slovakia in 2021 (Table 3), three of them with the epicentre on the territory of Slovakia

Table 2. List of earthquakes originated on the territory of Slovakia in 2021 with $M_L \geq 1.0$.

Date [YYYY-MM-DD]	Origin Time (UTC) [HH:MM:SS]	Lat. [°N]	Lon. [°E]	Depth [km]	M_L [NNSS]	I_0 [°EMS]	Region
2021-01-28	08:16:44.31	48.66	18.70	3	3.2	3	Vtáčnik Mts.
2021-02-02	19:37:47.29	48.26	17.43	0	1.2		Little Carpathians
2021-03-05	00:41:24.09	47.89	18.04	13	1.9		Šamorín – Komárno – Štúrovo
2021-03-09	15:08:37.63	49.24	19.74	12	1.4		High Tatras
2021-03-22	17:29:16.98	49.14	19.48	0	2.1		Liptov region
2021-03-30	09:19:41.75	48.69	22.14	0	1.1		Eastern Slovak Plain
2021-05-14	18:18:49.65	48.60	17.60	4	1.4		Little Carpathians
2021-06-19	18:04:31.29	48.57	17.55	2	1.5		Little Carpathians
2021-07-01	09:40:03.10	48.67	19.60	0	1.2		Vepor Mts.
2021-07-29	07:58:17.82	48.76	19.65	18	1.9		Vepor Mts.
2021-08-13	13:16:27.11	48.38	21.78	12	1.3		Zemplín Mts.
2021-08-29	21:57:30.22	47.77	18.18	0	2.0	3	Šamorín – Komárno – Štúrovo
2021-09-09	11:07:53.42	47.75	17.67	12	1.8		Šamorín – Komárno – Štúrovo
2021-10-03	13:41:36.62	48.71	18.61	0	1.1		Vtáčnik Mts.
2021-10-06	04:06:30.16	48.42	17.13	1	2.0	3	Záhorie region
2021-10-13	01:02:14.20	48.81	19.45	0	1.8	5	Upper Hron River region
2021-10-15	15:53:39.74	48.89	21.80	4	1.4		Vihorlat Mts.
2021-11-22	23:03:21.43	49.05	18.62	0	1.0		Rajecká dolina valley
2021-12-15	03:18:10.68	48.35	17.06	0	1.1		Little Carpathians
2021-12-31	05:36:50.09	47.79	18.17	2	1.0		Šamorín – Komárno – Štúrovo

Table 3. List of macroseismically observed earthquakes on the territory of Slovakia in 2021.

Date [YYYY-MM-DD]	Origin Time (UTC) [HH:MM:SS]	Lat. [°N]	Lon. [°E]	Depth [km]	M_L [NNSS]	I_0 [°EMS]	Region
2021-01-06	17:01:43.9	45.43	16.21	8	4.9	3*	Croatia
2021-01-28	08:16:44.3	48.66	18.70	3	3.2	3	Vtáčnik Mts.
2021-03-30	16:25:01.5	47.73	16.17	11	4.2	3*	Austria
2021-04-19	22:57:12.1	47.72	16.19	12	4.1	4*	Austria
2021-08-29	21:57:30.2	47.77	18.18	0	2.0	3	Komárno
2021-10-06	04:06:30.2	48.42	17.13	0	2.0	3	Záhorie region
2021-10-13	01:02:14.2	48.81	19.45	0	1.8	5	Upper Hron River region

* highest macroseismic intensity on the territory of Slovakia

(Fig. 3) and two of them on the territory of Austria and one of them on the territory of Croatia. All of these seven earthquakes were also seismometrically observed and processed. Intensities were estimated by the European Macroseismic Scale 1998 (EMS-98) introduced by *Grünthal (1998)*.

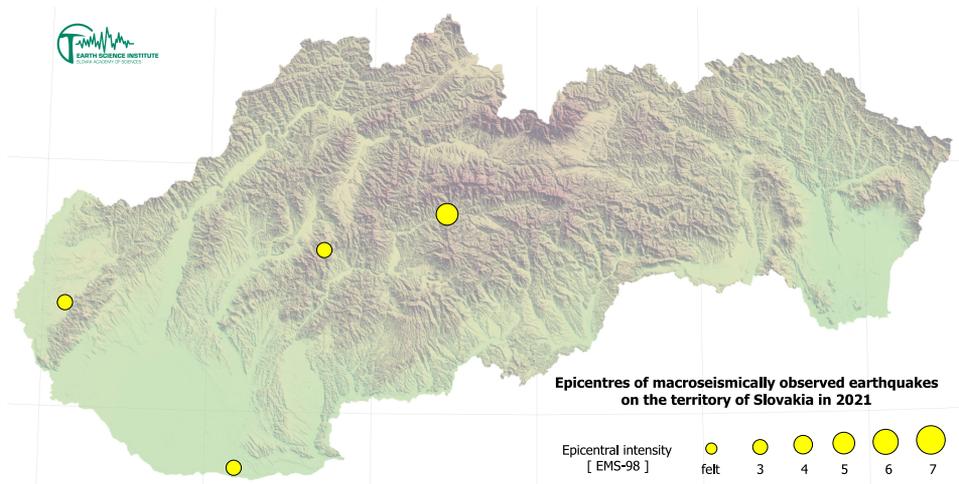


Fig. 3. Map of epicentres of macroseismically observed earthquakes on the territory of Slovakia in 2021. Diameters of the circles are proportional to epicentral intensity.

The earthquake on January 6 at 17:01 UTC with epicentre near Petrinja, Croatia and local magnitude 4.9 was macroseismically felt on 1 location within the territory of Slovakia (Table 4). 2 macroseismic questionnaires were filled. The maximum intensity on the territory of Slovakia was determined at 3° EMS-98.

The earthquake on January 28 at 8:16 UTC with epicentre in Vtáčnik Mountains between municipalities Prochot and Podhradie and local magnitude 3.2 was macroseismically felt on 29 locations (Table 5). 212 macroseismic questionnaires were filled. The epicentral intensity was determined at 3° EMS-98. The event was described like a weak swinging and few people described acoustic effects and shaking of light furniture.

The earthquake on March 30 at 16:25 UTC with epicentre near Wiener Neustadt, Austria and local magnitude 4.2 was macroseismically felt on 13 locations within the territory of Slovakia (Table 6). 72 macroseismic questionnaires were filled. People reported weak trembling in municipalities Bratislava, Pezinok, Modra and Šamorín. The maximum intensity on the territory of Slovakia was determined at 3° EMS-98.

The earthquake on April 19 at 22:57 UTC with epicentre near Wiener Neustadt, Austria and local magnitude 4.1 was macroseismically felt on 14 locations within the territory of Slovakia (Table 7). 188 macroseismic questionnaires were filled. People reported weak trembling in municipalities Bratislava, Pezinok and Šamorín. The maximum intensity on the territory of Slovakia was determined at 3–4° EMS-98.

The earthquake on August 29 at 21:57 UTC with epicentre near municipality Komárno and local magnitude 2.0 was macroseismically felt on 3 locations (Table 8). 30 macroseismic questionnaires were filled. The event was described as a moderate jolt. Some people reported acoustic effect like weak/moderate rumbling/detonation, rumble and shaking of light furniture. The epicentral intensity was determined at 3° EMS-98.

The earthquake on October 6 at 4:26 UTC with epicentre in Záhorie military district and local magnitude 2.0 was macroseismically felt on 2 locations (Table 9). 2 macroseismic questionnaires were filled. The epicentral intensity was determined at 3° EMS-98.

The earthquake on October 13 at 1:02 UTC with epicentre in Upper Hron River region near municipality Predajná and local magnitude 1.8 was macroseismically felt on 8 locations (Table 10). 41 macroseismic question-

Table 4. Macroseismic observations for January 6, 2021 earthquake, 17:01 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Bratislava	48.163	17.126	2	3

Table 5. Macroseismic observations for January 28, 2021 earthquake, 8:16 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Prievidza	48.772	18.626	53	3
Handlová	48.723	18.750	46	3
Žiar nad Hronom	48.582	18.853	18	3
Lovčica-Trubín	48.618	18.790	16	3
Janova Lehota	48.659	18.784	11	3
Nováky	48.725	18.544	9	3
Lehota pod Vtáčnikom	48.698	18.606	8	3
Cigeľ	48.716	18.645	4	3
Koš	48.745	18.581	4	3
Podhradie	48.668	18.175	4	3
Bojnice	48.786	18.593	3	3
Horná Ždaňa	48.569	18.751	3	3
Partizánske	48.641	18.589	3	3
Kosorín	48.650	18.808	2	3
Prestavky	48.585	18.756	2	3
Zemianske Kostofany	48.690	18.521	2	3
Banská Bystrica	48.733	19.143	4	3
Hliník nad Hronom	48.536	18.778	1	3
Horná Trnávka	48.579	18.759	1	3
Hostie	48.483	18.456	1	3
Hronec	48.759	19.561	1	3
Lutila (Žiar nad Hronom)	48.615	18.842	1	3
Oslany	48.618	18.502	1	3
Partizánske	48.641	18.589	1	3
Turčianske Teplice	48.864	18.857	1	3
Sebedražie	48.733	18.631	5	felt

Table 5. Continued from the previous page.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Nová Lehota	48.674	18.733	4	felt
Prochot	48.612	18.708	2	felt
Kopanice-Prievidza	48.781	18.641	1	felt

Table 6. Macroseismic observations for March 30, 2021 earthquake, 16:25 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Bratislava 5	48.068	17.119	19	3
Bratislava 1	48.145	17.103	12	3
Bratislava 2	48.140	17.174	12	3
Bratislava 4	48.165	17.073	10	3
Bratislava 3	48.207	17.147	7	3
Pezinok	48.298	17.270	3	3
Modra	48.347	17.313	2	3
Šamorín	48.025	17.339	2	3
Chorvátsky Grob	48.226	17.262	1	3
Dunajská Lužná	48.083	17.265	1	3
Malinovo	48.141	17.313	1	3
Rovinka	48.098	17.237	1	3
Hamuliakovo	48.039	17.251	1	felt

Table 7. Macroseismic observations for April 19, 2021 earthquake, 22:57 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Komárno	47.766	18.118	1	4
Hamuliakovo	48.039	17.251	1	3–4
Bratislava 4	48.165	17.073	47	3
Bratislava 5	48.068	17.119	42	3
Bratislava 2	48.140	17.174	36	3
Bratislava 1	48.145	17.103	29	3
Bratislava 3	48.207	17.147	17	3
Pezinok	48.298	17.270	6	3

Table 7. Continued from the previous page.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Šamorín	48.025	17.339	4	3
Slovenský Grob	48.256	17.279	1	3
Topoľčany	48.561	18.174	1	3
Zálesie	48.169	17.274	1	3
Čenkovce	48.106	17.434	1	3
Nová Ves pri Dunaji	48.191	17.362	1	felt

Table 8. Macroseismic observations for August 29, 2021 earthquake, 21:57 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Komárno	47.766	18.118	27	3
Aňalské Záhrady	47.941	18.149	1	3
Aňala	47.957	18.136	2	felt

Table 9. Macroseismic observations for October 6, 2021 earthquake, 4:06 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Borinka	48.264	17.021	1	3
Modra	48.347	17.313	1	3

Table 10. Macroseismic observations for October 13, 2021 earthquake, 1:02 UTC.

Locality	Lat. [°N]	Lon. [°E]	No. of questionnaires	<i>I</i> [°EMS-98]
Predajná	48.82	19.463	18	5
Dubová	48.815	19.427	3	4–5
Jasenie	48.863	19.447	3	4–5
Podbrezová	48.815	19.522	1	4–5
Lopej	48.818	19.496	6	4
Nemecká	48.812	19.435	6	4
Ráztoka	48.821	19.403	3	4
Pohronský Bukovec	48.835	19.379	1	felt

naires were filled. The epicentral intensity was determined at 5° EMS-98. People reported weak and moderate trembling; rumble, shaking and shifting of light furniture, acoustic effect was like a moderate rumbling or detonation.

6. Conclusion and discussion

The NNSS is operated by the ESI SAS, Bratislava. Data from all stations (except station HRB) are transferred in real-time to the data centre at Bratislava. Data processing and routine analysis are performed digitally by interactive seismological software Seismic Handler. Digital data are accessible both on-line and off-line in standard data format. So-called Seismo Reports of seismic events recorded by NNSS are published on the web page of the ESI SAS <http://www.seismology.sk/SeismoReports/reports.html>.

Maintenance of the permanent stations in the year 2021 was affected by COVID-19 pandemic situation but the employees of the ESI SAS did their best to keep all seismic stations in operation.

We continued with the successful cooperation CE3RN (*Lenhardt et al., 2021*) and with co-maintenance of temporary seismic stations in the cooperation PACASE (*Hetényi et al., 2019*) too.

Epicentres and local magnitudes were determined for 88 earthquakes originated on the territory of Slovakia in 2021. Weak seismic activity was recorded from several seismic source zones: Little Carpathians, Komárno, Vtáčnik Mts., Vihorlat Mts., Vepor Mts. and Záhorie region.

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