FORTY YEARS NATIONAL OPERATIVE TELEMETRIC SYSTEM FOR SEISMOLOGICAL INFORMATION

L. Christoskov, L. Dimitrova, D. Solakov, S. Simeonova

National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., bl. 3, Sofia 1113, Bulgaria, e-mail: lidim@geophys.bas.bg

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Abstract. National Operative Telemetric System for Seismological Information (NOTSSI) is operating since 1980. At the beginning, the real-time data transfer from the stations to the data center was organized through analog telephone lines and earthquake parameters were evaluated manually. In 2006 both the seismological network and the data center were upgraded with state-of-the-art digital equipment and automatic data processing was organized. More than 12 TB processed and raw data are archived during the last 12 years in PASSCAL, mini SEED continues data formats and in event oriented CSS format. The data completeness exceeds 99% and the rare loss of data is mainly due to communication outages. The maintenance of the network and the data center is organized in such a manner that the upgrade of the equipment and the software updates do not affect the performance of the Operating Center. During the last 12 years the number of seismic stations increased significantly and at the end of 2019 it is 40. Currently the seismic center is upgraded with software for acquisition and automatic data processing SeisComP3 that is widely used in seismological community and data centers.

Key words: National Operative Telemetric System for Seismological Information, Bulgarian Seismological Network, Seismic Data Centre, SeisComP3

Introduction

Bulgaria is an earthquake prone country. Over the past centuries, Bulgaria has experienced strong earthquakes. The first well documented earthquake on the territory of Bulgaria is the 1st c BC quake occurred in the Black Sea near the town of Kavarna. In historical aspect, it is worth to mention the 1818 (8-9 MSK) and the 1858 (MS=6.3, I0=9 MSK) earthquakes occurred near the city of Sofia. Some of the Europe`s strongest 20th century earthquakes occurred in Bulgaria (at the beginning of the 20th century from 1901 to 1928 five earthquakes with magnitude larger than or equal to 7.0 occurred on the territory of

Bulgaria) – 30.03.1901 Shabla earthquake with magnitude Ms=7.2; 04.04.1904 Kresna earthquakes with Ms magnitudes 7.1 and 7.8, `14.6.1913 G. Orjahovitsa earthquake with magnitude Ms=7.0 and two earthquakes near the city of Plovdiv in 1928 - 14.04 with magnitude Ms=6.8 and 18.04 with magnitude Ms=7.0.

The seismological observations on the territory of Bulgaria have traditions of more than 120 years. The beginning of Bulgarian seismology dates back to 1891. At that time Spas Watzof, the director of Central Meteorological Station in Sofia, organized network of correspondents for observation of felt earthquakes in Bulgaria (Watzof, 1902). Watzof formed a proto-type of macro-seismic bulletin (Christoskov, 2007) containing: time of perceived shaking, locality, direction of impact, observed effects, intensity assessed by Rossi-Forel scale till 1912 and Forel-Mercalli since then. The first bulletin including data for Central Balkan earthquakes occurred in the 19th century was published in 1902 (Watzof, 1902). Afterwards, the bulletins have been published yearly up to 1959 .

The period of Bulgarian historical era ends in 1905 when the seismograph of Omorri-Boch type was installed in the first Seismological Station in the town of Sofia. The same year four seismoscopes of Agamenonne type were installed in Sofia, Petrohan, Rila monastery and the town of Kazanlak.

In the period 1961-1979, six seismic stations were run. These are stations in Dimitrovgrad, Pavlikeni, Musomishta, Kardjali, Preselentsi and Vitosha (DIM, PVL,MMB, KDZ, PSN and VTS). The strong 1977 Vrancea (Romania) intermediate depth earthquake with seismic moment magnitude Mw=7.4-7.5 and its negative impact on the territory of the northern Bulgaria (loss of human lives and destroyed properties) force the development of a new strategy for monitoring and investigation of the seismicity in Bulgaria and surroundings (Samardjiev et al.,1980). At the end of 1980 the National Operative Telemetric System for Seismological Information was put in operation. It was a key point in seismic monitoring in Bulgaria. The major tasks of NOTSSI are:

- To provide reliable continuous recording and transfer of seismological data;
- To ensure rapid notification of the governmental authorities, media and broad public in case of felt or damaging earthquakes on the territory of Bulgaria;
- To provide a modern basis for seismological studies in Bulgaria.

NOTSSI was a part of the Geophysical Institute (GPhI) of the Bulgarian Academy of Science (BAS) up to 2010 and of the National Institute of Geophysics, Geodesy and Geography (NIGGG) of BAS after that.

Analogue Seismological Network and Data Center

At the beginning, NOTSSI operated with 6 seismic stations. Over the next two decades, the seismic network was developed and new stations were run. At the end of the last century NOTSSI consisted of 21 short period one component seismic stations deployed on the territory of the country (Christoskov et al., 2012). The analogue information from all stations was transferred in real time mode by telephone lines to the Seismological Data Center of NOTSSI at the Geophysical Institute. Seismic data were visualized on paper drums with two levels of amplification to achieve larger dynamic range of the records. An automated processing system based on a PDP 11/34 mini-machine was built at the Data center in 1981. Analog signals were digitized and processed in near real time and an archive of detected and localized seismic events was created.

In routine practice the main parameters of the earthquakes were estimated manually using S minus P time differences. The wave amplitudes and signal duration were used for magnitude evaluation.

Later the DHypo computer code (Solakov and Dobrev, 1987) was involved in the seismological practice. The input information for the calculation of the earthquake parameters are the P and/or S onsets, the maximum amplitude of the P and/or S phases and/or signal duration.

Digital Seismological Network

Modernization and digital upgrading of NOTSSI started in 1996. First, station Vitosha (VTS, since 1979) was included in the MEDNET network (within international project “PLATO-1”) and was updated with VBB seismometer STS-1 and Quanterra 380 DAS (Christoskov et al., 1996).

In the period 2001-2004, with the financial support of the Permanent Commission for Prevention of the Population from Natural Disasters and Catastrophes and in the frame of the European project MEREDIAN-2, two digital stations (Plovdiv (PLD) and Yambol (JMB)) were put in operation. A digital real-time data communication between the three digital stations – VTS, PLD and JMB and the Data Center at the Geophysical Institute in Sofia was created. A real-time data exchange with international (MEDNET, ORFEUS-European Center for Digital Seismological Data, NEIC etc.) and regional seismological centers (Austria, Slovenia, Czech Republic, Romania, etc.) was established. Bulgaria becomes a part of the European and world digital seismological data structures.

At the end of 2005, by the financial support of the former Ministry of Emergency Situations, digital equipment and software were purchased from the company “Refraction Technology” Inc. (http://reftek.com). In 2006 the digital seismological equipment was installed at all stations of the network and a data center with real-time automatic and interactive data processing was organized.

During the next 12 years the number of seismic stations increased thanks to several projects with NPP “Kozloduy” PLC, National Scientific Fund and the financial support of the National Institute of Geophysics, Geodesy and Geography. At the end of 2019 the number of the seismic stations of the National Seismic Network and the two Local Seismological Networks - “Provadya” and “Kozloduy” is 25 (Table 1). After 2012 in the frame of trans-regional project “Danube Cross-border system for Earthquakes Alert (DACEA)” was installed fifteen stations on the territory of the North Bulgaria and is operated by NOTSSI (Table 2). These stations are part of Bulgarian Romanian trans-border Early Warning System.

In Tables 1 and 2 are presented lists of seismic stations, seismological equipment and data recording information of the Bulgarian seismological network with following parameters:

Table 1. Seismic stations of the National Seismic Network and Local Seismological Network – LSM "Kozloduy" and LSM "Provadya" and their equipment

Station Name	BG Code	INT Code	Lat(°) N	Long(°) E	Elev [m]	**Seismometer** *Accelerometer*	Compo-nents	Data acquisit. system/ sampling rate
Dimitrovgrad	DIM	DIM	42.04	25.58	144	**S-13**	3C	Reftek 130-01/ 100 sps
Yambol	JMB	JMB	42.49	26.53	210	**GMT-40T/30s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Kurdzhali	KDZ	KDZ	41.63	25.34	335	**3ESPC/120s**	3C	Reftek 130-01/ 100 sps
Krupnik	KKB	KKB	41.84	23.13	439	**GMT-40T/30s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Musomishta	MMB	MMB	41.55	23.75	632	**STS2** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Panagyurishte	PGB	PGB	42.51	24.17	574	**GMT-40T/30s**	3C	Reftek 130-01/ 100 sps
Plovdiv	PLD	PLD	42.15	24.75	198	**GMT-40T/30s**	3C	Reftek 130-01/ 100 sps
Provadya	PRD	PRD	43.16	27.41	120	**GMT-40T/30s**	3C	Reftek 130-01/ 100 sps
Preselentsi	PSN	PSN	43.64	28.13	185	**KS 2000/60s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Pavlikeni	PVL	PVL	43.12	25.17	218	**3ESPC/120s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Rozhen	RZN	RZN	41.69	24.74	1735	**GMT-40T/30s**	3C	Reftek 130-01/ 100 sps
Sofia	SOF	SOF	42.68	23.37	570	**S-13**	3C	Reftek 130-01/ 100 sps
Strazhitsa	SZH	SZH	43.26	25.98	331	**3ESPC/60s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Vitosha	VTS	VTS	42.61	23.23	1390	**3ESPC/120s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Malo Peshtene	MPE	MPEP	43.36	23.74	344	**RefTek 151/120s** S13	3C, 1C	Reftek 130-01/ 100 sps
Plana	PLN	PLNA	42.48	23.42	1245	**3ESPC/120s** *131A-02/3*	3C	Reftek 130-01/ 100 sps
Tran	TRAN	TRAN	42.83	22.65	706	**RefTek 151/30s** *147-01/3*	3C	Reftek 130-01/ 100 sps
Oriahovo	ORH		43.73	23.97	231	**S-13**	3C	Reftek 130-01/ 100 sps
Valchedram	VLD	VALD	43.69	23.43	93	**S-13 -Borehole**	1C	Reftek 130-01/ 100 sps
Avren	AVR	AVR	43.12	27.67	306	**Geophone GS 11D**	3C	Reftek 130-01/ 100 sps
Roiak	ROIA	ROIA	43.09	27.38	356	**Geophone GS 11D**	3C	Reftek 130-01/ 100 sps
Bozvelijsko	BOZ		43.10	27.48	37	**Geophone GS 11D**	3C	Reftek 130-01/ 100 sps
Dobrina	DOB		43.18	27.46	230	**Geophone GS 11D**	3C	Reftek 130-01/ 100 sps
Nevsha	NEF	NEF	43.26	27.27	359	**S-13**	3C	Reftek 130-01/ 100 sps
Balsha	BLSH	BLSH	42.86	23.28	739	**Reftek151B/30s**	3C	Reftek 130-01/ 100 sps

Station name – the name of the nearest settlement where the station is located to;

Code – the unique international code of the station;

Lat,N, Long,E , Elev,m – geographic coordinate and elevation of the station;

Seismometer/Accelerometer – the type of sensors installed. Seismometers are installed in several stations, in others – seismometers and accelerometers; and the last 7 stations mentioned in the table 2 are equipped with accelerometers EpiSensor;

Component – the type of data registration – 3 components (Z, NS, EW) or 1 component (Z);

Data acquisition system/ sampling rate – the type of digitizer and the sampling rate of the real-time transferring data;

Real-time data transfer is realized via Virtual Private Network (VPN) of the Bulgarian Telecommunication Company (BTC).

The Bulgarian Seismological Network has international code *BS* and *Digital Object Identifier (DOI): 10.7914/SN/BS (https://doi.org/10.7914/SN/BS).*

Table 2. DACEA seismic stations on the territory of the North Bulgaria and their equipment

Station Name	Code	Lat(°) N	Long(°) E	Elev [m]	Seismometer *Accelerometer*	Compo nents	Data acquisit. system/ sampling rate
Belogradchik	BLKB	43.62	22.67	650	**KS2000** *EpiSensor*	3C	Bazalt
Pleven	PLVB	43.39	24.62	199	**KS2000** *EpiSensor*	3C	Bazalt
Loznitsa	LOZB	43.37	26.59	342	**KS2000** *EpiSensor*	3C	Bazalt
Razgrad	RAZG	43.57	26.508	383	**KS2000** *EpiSensor*	3C	Bazalt
Shabla	SHAB	43.54	28.60	430	**KS2000** *EpiSensor*	3C	Bazalt
Elena	ELND	42.93	25.87	334	**KS2000** *EpiSensor*	3C	Bazalt
Kubrat	KUBB	43.80	26.49	261	**KS2000** *EpiSensor*	3C	Bazalt
Balgarevo	KALB	43.40	28.43	121	**KS2000** *EpiSensor*	3C	Bazalt
Dobrich	DOBAM	43.58	27.83	246	*EpiSensor*	3C	Bazalt
Montana	MNNAM	43.41	23.23	240	*EpiSensor*	3C	Bazalt
Vidin	PLVAM	43.95	22.85	880	*EpiSensor*	3C	Bazalt
Belene	RAZAM	43.64	25.12	820	*EpiSensor*	3C	Bazalt
Ruse	RUSAM	43.85	25.96	100	*EpiSensor*	3C	Bazalt
Silistra	SILAM	44.10	27.27	840	*EpiSensor*	3C	Bazalt
Veliko Tarnovo	VETAM	43.08	25.64	224	*EpiSensor*	3C	Bazalt

The location of all seismic stations of the Bulgarian seismological network is presented in Fig. 1.

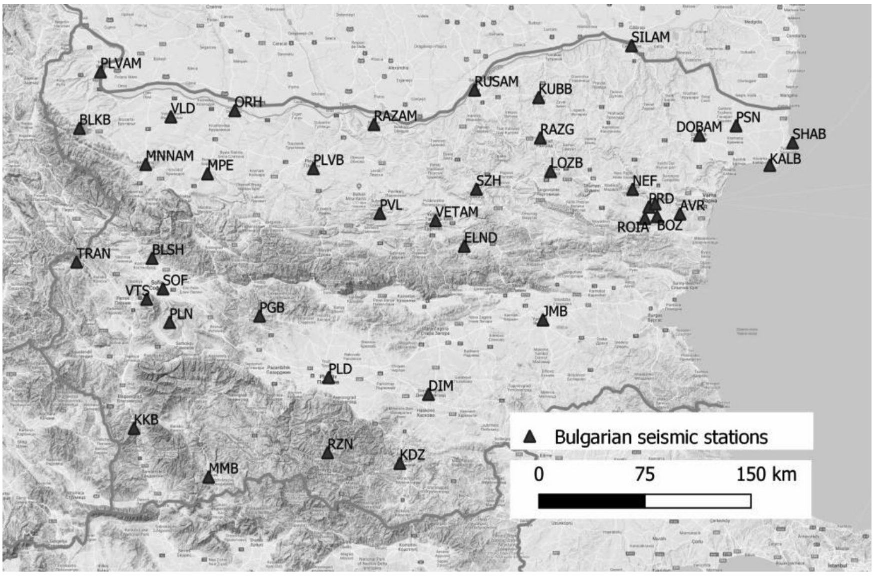


Fig. 1. Map of the seismic stations of Bulgarian Seismological Network

Data Centre

The Data Centre is equipped with Seismic Network Data Processor Software (SNDP) (Haikin and Kushnir, 2005) which provides real-time data acquisition, automatic processing and interactive analysis of the seismological data registered by the stations of National Seismological Network and number of stations from neighbor countries. The SNDP is a set of asynchronous interactions of many processes. The Continuous seismic data receiving process is designed to receive and store the incoming data in a 7-day disk loop buffer. It ensures access to stored data for all client processes working both in automatic and interactive modes. The Real-time detection is carried out independently for each station and determines signal to noise ratio (SNR), frequency band of detection and the onset time. The detection is implemented by adaptive broadband and traditional STA/LTA detectors in several narrow frequency bands. The Estimator process reveals seismic phases of detected signals estimate their parameters and identify their types. The Estimator sends a message to the process of association and location of seismic source. The Associator of phases and locator of seismic sources associate the estimated phases to a seismic source by method of node sorting and minimization of residuals. Daily bulletins with the coordinates and parameters of seismic event, and its associated phases are produced as results from the automatic data processing. The geographic coordinates of the seismic events are drawn on a map and published in real-time.

The real-time seismic data are fed into the automatic data processing by two protocols – RTPD and SeedLink. RTPD protocol acquires the data recorded by the 25-th seismic stations all over the country (Table 1) and the SeedLink – the DACEA seismic stations in the North Bulgaria. SeedLink protocol is used for data exchange with the seismic centers of the neighbor countries and various International Data Centers.

During the last 12 years the seismological equipment and processing software have been periodically upgraded with the latest releases. The upgrade procedures have never affected the performance of the Network and the Data Centre due to both the high professional skill of the maintenance staff and the excellent organized support services.

More than 12 TB processed and raw data have been archived during the last 12 years in PASSCAL and mini SEED continues data formats and in event oriented CSS format. The data completeness exceeds 99% and the loss of data in rare cases was mainly due to communication outages.

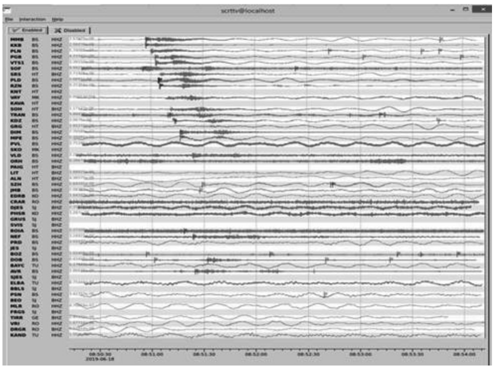
Current state of the Data Centre

Currently, the National Data Centre is upgraded with SeisComPro software for automatic data processing that is widely used in seismological community and data centers. SeisComPro is developed by German company Gempa (https://gempa.de). The software is an extension to SeisComP3 community package distributed by GFZ Potsdam. The main features provided by the SeisComp3 package are: *data acquisition, quality control and recording; real-time data processing and exchange; network status monitoring; automatic and interactive event detection and location; event parameter archiving; easy access to relevant information about stations, waveforms and recent earthquakes*.

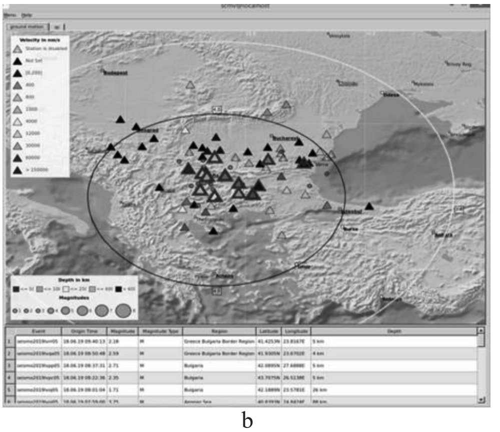
The SeisComPro is developed in order to improve the local earthquake and microseismicity monitoring. To upgrade the National Data Center we have installed free SeisComP3 software package as a base and three commercial modules of the SeisComP Pro.

The module *scanloc* is developed to monitor the natural and induced seismicity within the both small and large seismic networks. The module uses a cluster search algorithm to associate P phase detections to one or many potential earthquake sources. In a second step S-phases are also associated and used for earthquake location. Fig. 2 represents three steps of the execution of the scanloc procedure – real-time automatic P-phase picking (upper left), waveform propagation after event detection (upper right) and automatic event location parameters (down left).

The module *sceval* is designed to evaluate the event locations produced by the scanloc module (fig. 3). It automatically discriminates real earthquakes from fake solutions and marks them even if they are very weak. Such a way the monitoring system can be tuned not to miss small events.



a



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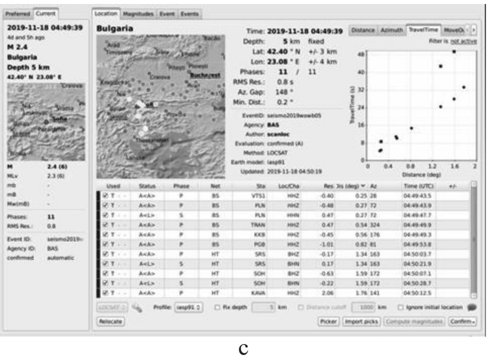

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Fig 2. The execution of the scanloc module: a – Upper left picture - Automating P –phase picking; b – Upper right picture - Waveform propagation after event detection; c – Down left picture - Automatic event location

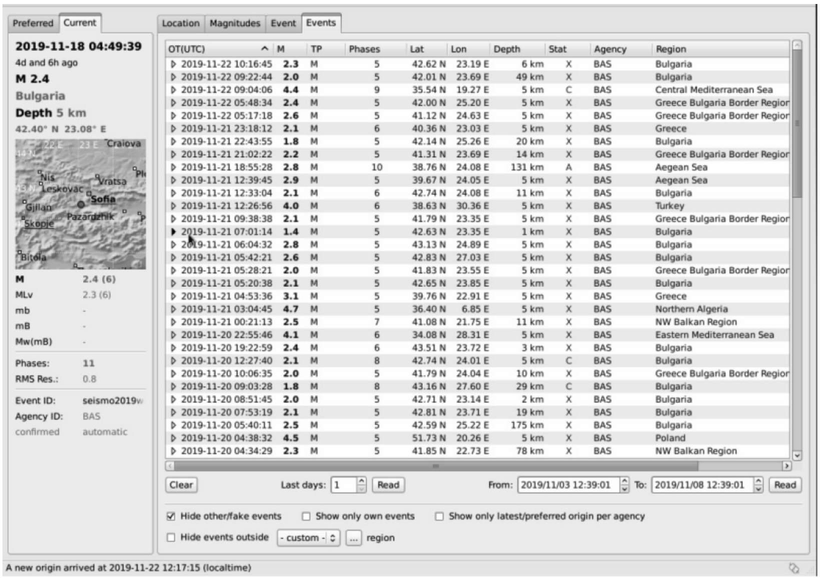
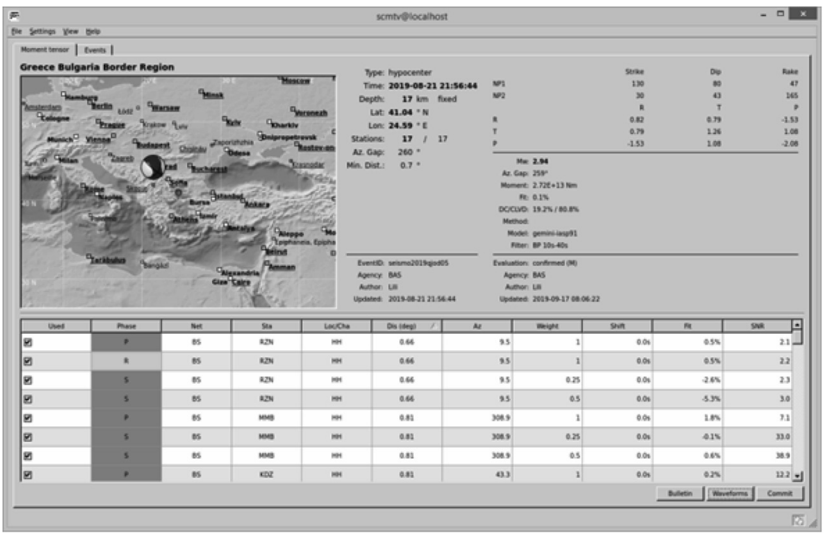


Fig. 3. List of event locations evaluated by the sceval module

The module *mt* computes and analyzes moment tensors (fig. 4). The moment tensor inversion technique uses a combination of several seismic wave types, time windows and frequency bands carefully chosen based on event magnitude and station distance.



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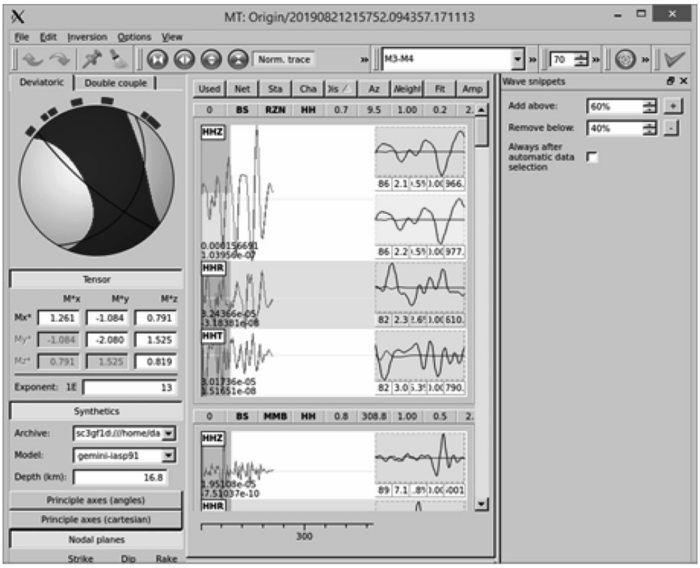

b

Fig 4. An example of the automatic moment tensor solution produced by the **mt** module for the 21.8.2019 earthquake with parameters To=21:56:44, coordinates 41.04N, 24.59 E and Mw=2.94.

Conclusions

National Operative Telemetric System for Seismological Information is in continuous exploitation during the last 40 years. The hardware and software are maintained at a high and up-to-date level to meet the requirements of a nationally responsible institution: reliable registration and processing of earthquakes on the territory of Bulgaria and surroundings in order to provide reliable information to the authorities, general public and scientific community.

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Четиридесет години Национална оперативна телеметрична система за сеизмологична информация

Л. Христосков, Л. Димитрова, Д. Солаков, С. Симеонова

Резюме. Българската сеизмологична реално-временна мрежа и Националният център за данни работят от 1980 г. В началото данните от сеизмичните станции са пренасяни в реално време чрез аналогови телефонни линии до центъра за данни, а параметрите на регистрираните сеизмични събития са обработвани ръчно. През 2006 г. както сеизмологичната мрежа, така и информационният център бяха модернизирани със съвременно цифрово оборудване и беше организирана автоматична обработка на данни. През последните 12 години са архивирани повече от 12 ТВ обработени и сурови данни в PASSCAL, mini SEED и в CSS формати. Пълнотата на архивираните данни надвишава 99%, а загубата на данни се дължи главно на прекъсвания на комуникацията. Поддръжката на мрежата и центъра за данни е организирана по такъв начин, че надграждането на оборудването и обновяването на софтуера не влияят върху оперативната дейност. През последните години броят на сеизмичните станции нараства значително и в края на 2019 г. е 40. В момента сеизмичният център е модернизиран със софтуер SeisComP3 за реално времеви трансфер и автоматична обработка на данни, който се използва широко в сеизмологичната общност и центровете за данни.