Operational Procedures of Agencies Contributing to the ISC

Seismic Monitoring and Data Processing at the National Institute for Earth Physics – Romania

Constantin Ionescu, Mihaela Popa,
Cristian Neagoe, Daniela Veronica Ghica

National Institute for Earth Physics, Măgurele
Romania

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6

Operational Procedures of Contributing Agencies

6.1 Seismic Monitoring and Data Processing at the National Institute for Earth Physics – Romania

Constantin Ionescu, Mihaela Popa, Cristian Neagoe, Daniela Veronica Ghica

National Institute for Earth Physics, Măgurele, Romania

Constantin Ionescu

Mihaela Popa

Cristian Neagoe

Daniela Veronica Ghica

6.1.1 Local Seismicity

Located in the south-eastern part of Europe, Romania is a country with moderate seismicity, generated by the occurrence of both crustal and intermediate-depth earthquakes (Fig. 6.1). In addition to local seismicity, the territory is affected by major earthquakes produced in the North Bulgaria or the Black Sea regions (e.g.. 1892 – M7.0 – Dulovo; 1901 – M7.2 - Black Sea (Balchik); 1956 – M5.5 – Black Sea; 2009 – M5.0 – Black Sea).

The intermediate-depth seismic source located at the Carpathians Arc Bend, in the Vrancea region, is dominating the seismicity in Romania in terms of the rate of energy release, concentration and persistence of earthquake generation. The Vrancea region is an area of continental convergence characterized by at least three tectonic units in contact: the Eastern European Plate and the Intra-Alpine and Moesic subplates (*Constantinescu et al.*, 1976). The strongest seismic activity is concentrated at intermediate depths (50–200 km), in an old subducted plate, descending almost vertically at present. The average generation of two to three shocks of $M_W > 7.0$ per century (e.g. 10 November 1940 ($M_W = 7.7$), 4 March 1977 ($M_W = 7.4$) and 30 August 1986 ($M_W = 7.1$) in the previous century) in a very small focal volume implies a high rate of active deformation (about 3.5×10^{-7}/year, *Wenzel et al.*, 1999) which is not found in the observed deformation of the overlying crust. The Vrancea major earthquakes usually have a high impact on over two thirds of Romanian territory and over large areas in Europe.

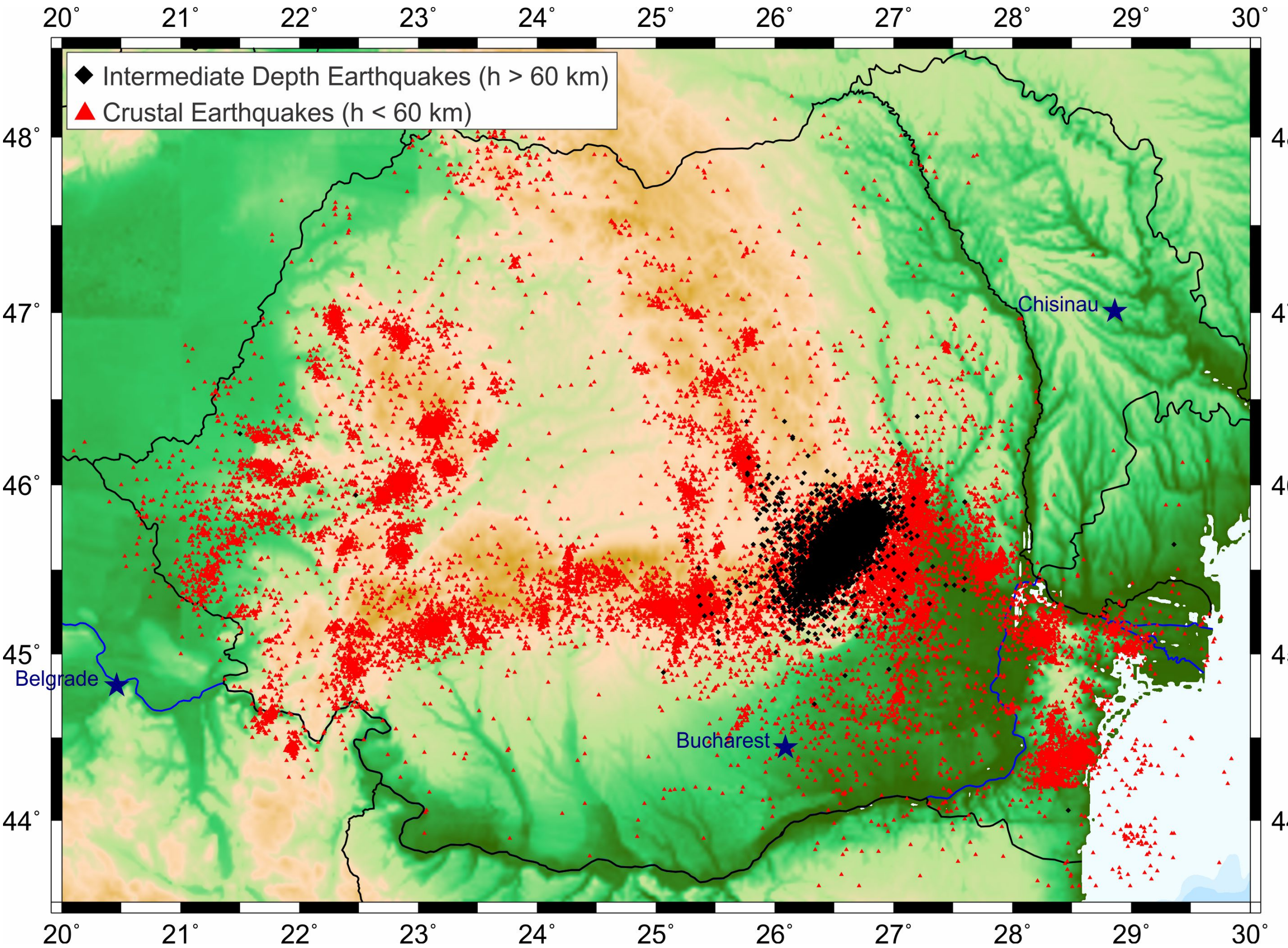

Figure 6.1: *Local Seismicity (h – depth, red – shallow events, black – intermediate-depth events) according to the Romanian catalogue (*Oncescu et al.*, 1999 – updated on* `http://www.infp.ro`*).*

Crustal seismic activity is generally moderate, with the spatial distribution of epicenters characterizing the contact areas between the major tectonic units. The earthquake foci are located at depths between 5 and 30 km. The radiated seismic energy and intensity are low and the earthquake generation is sometimes accompanied by numerous aftershocks.

6.1.2 Short History and Current State of the Seismic Network

Romania was one of the first countries worldwide involved in seismic monitoring. The first Romanian station (among the first stations in Europe) started to operate in 1888 in Bucharest, when Academician Stefan C. Hepites installed a microseismoscope Guzzanti and a seismometrograph Tacchini in the Meteorological Institute's building (BUC station). In 1902, the Bucharest seismic station was upgraded by installing two new horizontal Bosch smoked-paper seismographs.

In 1935, Professor Gh. Demetrescu established the Romanian Seismological Service which was in operation until 3 January 1977. During its existence, the Service operated under the coordination of various geophysical organizations in Romania. Consequently, between 1935 and 1977 significant development of the seismological network took place in Romania. New stations have been deployed as follows: Mainka-Demetrescu smoked-paper instruments were installed in Bucharest-Filaret (BUC, 1940), Vrincioaia (VRI, 1954), Cimpulung-Muscel (CMP, 1943), Focsani (FOC, 1942), Iasi (IAS, 1951), Timisoara (TIM, 1962),

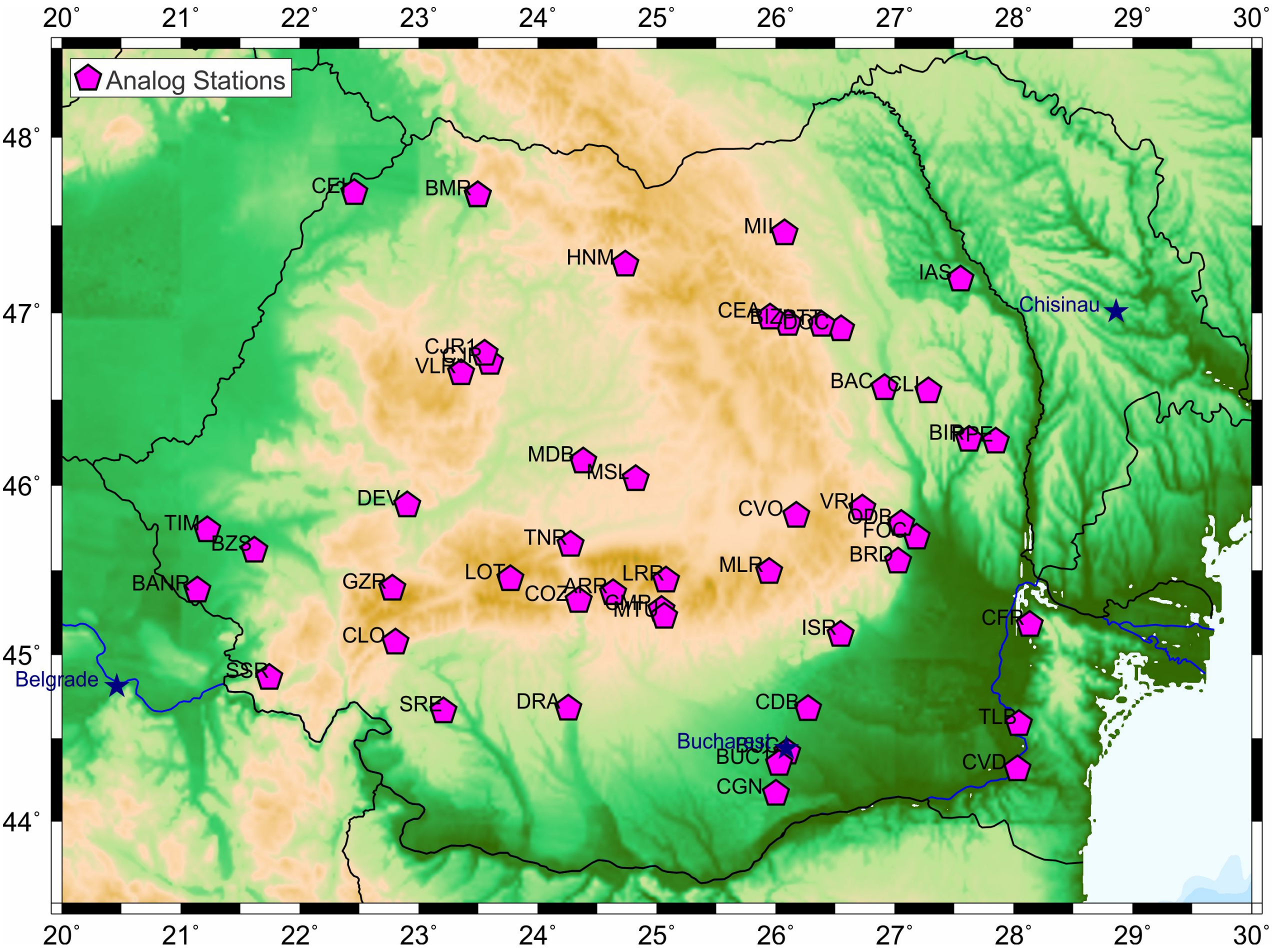

Figure 6.2: Analogue Station Network

Bacau (BAC, 1942) and Cluj (CJR, 1964); Galitin, Vegik and Alfany photographic paper instruments and DD1 paper and ink instruments were installed at the stations in Bucharest (BUC), Bacau (BAC), Iasi (IAS), Cimpulung Muscel (CMP), Focsani (FOC), Cheia-Muntele Rosu (MLR, 1974), Deva (DEV, 1975), Sasca Montana (SSR, 1968) and Gura Zlata (GZR, 1971).

On 3 January 1977, the Center for Earth Physics (CFP) was established, taking over the existing infrastructure developed in the field of Earth Physics. After the major $M_W = 7.4$ Vrancea earthquake of 4 March 1977, CFP was the recipient of UNDP-UNESCO aid that materialized through the purchase of modern seismic equipment. Between 1977 and 1982, Teledyne Geotech seismic stations, equipped with S13 sensors, were installed in 18 locations: Bordeşti (BRD), Carcaliu (CFR), Călugăreni (CGN), Cheia-Muntele Roşu (MLR), Coloneşti (CLI), Istriţa (ISR), Popeni (PPE), Sfânta Ana (AAR), Topalu (TLB), Vrâncioaia (VRI), Matau (MTU), Cozia (COZ), Strehaia (SRE), Closani (CLO), Valea Ierii (VLR), Heniu Mare (HNM), Ceahlau (CEA) and Covasna (CVO). Additionally, DD1 stations were deployed in the locations of Iasi (IAS), Bacau (BAC), Focsani (FOC), Vrincioaia (VRI), Carcaliu (CFR), Cimpulung-Muscel (CMP), Deva (DEV), Gura Zlata (GZR), Sasca Montana (SSR), Carei (CEI), Medias (MDB), Baia Mare (BMR), Cluj (CFR), Timisoara (TIM), Buzias (BZS), Dragasani (DRA), Piatra Neamt (PTT) and Odobesti (ODB). Figure 6.2 shows the geographical distribution of the analogue seismic stations on Romanian territory.

Over time, the Romanian seismic network has been continuously increased during the last period of

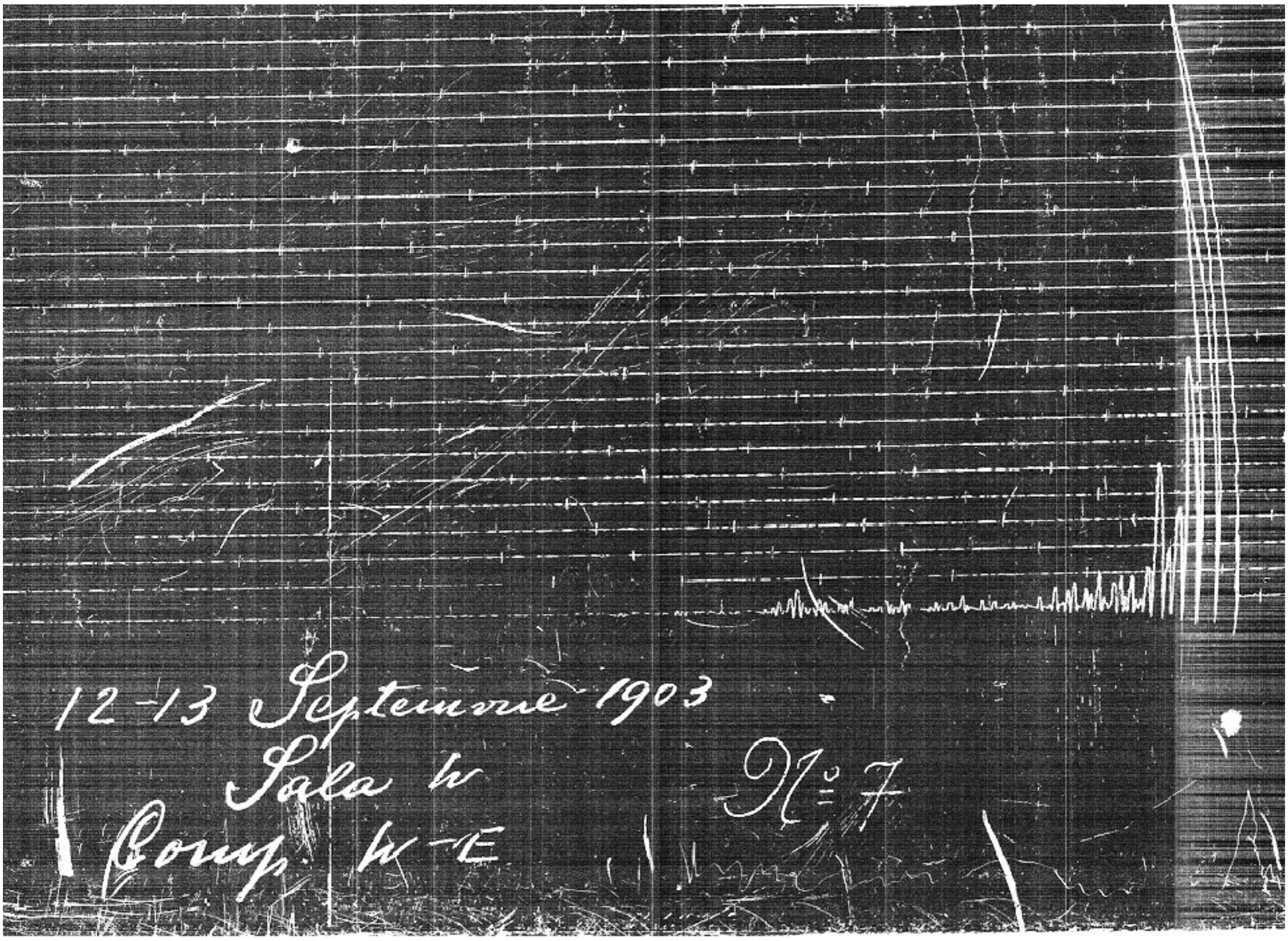

Figure 6.3: *Bosch mechanical pendulum seismogram recorded by the EW component for the Vrancea earthquake of 13 September 1903 at 10:02 GMT (M = 6.3). Half of the motion trace is available (scanned seismogram).*

operation of the analogue seismic station network to 48 stations, the range of seismometer types varying from Mainka, Mainka modified, Vegik-M, Galitin, Kirnos, Alfani, S5S, Hiller to DD1 and S13. In 1991, the data began to be digitally recorded, while the analogue recordings were maintained in parallel for a period of time. The last 5 analogue stations were decommissioned in 2017. The archive of analogue seismograms contains more than one million seismograms and includes recordings on smoked paper (Mainka-Demetrescu instruments), photographic paper (Galitin and Alfany instruments) and ink on paper. This archive contains seismograms dating from 1900. During the last years, over 5000 smoked and photographic paper seismograms, recorded by 5 seismic stations, were scanned and prepared for digitization (Figure 6.3). A database of the analogue seismograms is currently under construction; it will include scanned seismograms, information related to the seismic bulletins, publications and historical references.

Another important step for seismic monitoring in Romania was the installation of the strong-motion network between 1995 and 1997. 32 K2 accelerometers were deployed on the national territory in cooperation with the University of Karlsruhe, Germany, in the framework of the project "Strong Earthquakes: A Challenge for Geosciences and Civil Engineering".

In 1995, an analogue seismic sub-network was installed in Southwestern Romania, in order to monitor the intense crustal seismic activity observed in this region. The analogue data recorded with this sub-network was digitized (50 sps, 16 bits) in real time at Timisoara Observatory, forwarded to the Data Center in Măgurele and integrated with the rest of the data recorded by the Romanian network. At that time, an automated and networked seismological software (SAPS – *Oncescu et al.*, 1996), initially dedicated to analogue telemetry stations, was used both at Măgurele and Timisoara Observatory for on-line digital acquisition and seismic data processing, rapid earthquake location and magnitude computation.

Since 2000, the Romanian Seismic Network (RSN) has been widely expanded in order to monitor worldwide seismicity, by using digital stations (6 chs, 24 bits/26 bits) with real-time data transmission to the National Data Center (NDC) in Măgurele. Presently, RSN operates 117 single broadband and short-period stations (Figure 6.4), sending real-time data via satellite or internet connection to the NDC in Măgurele, and two seismo-acoustic arrays. Furthermore, 8 observatories (Bucovina, Buzias, Deva, Eforie, Muntele Rosu, Plostina, Vrancioaia and Timișoara) are in operation in the framework of RSN; different geophysical equipment are installed at these observatories to monitor seismicity and various precursors. A varied range of instrumentation, provided by different manufacturers, is used within the RSN: short-period sensors (Teledyne-Geotech S13 SH-1, GS21, Mark Products - l4c, L22, Kinemetrics – Ranger) and broadband sensors (Guralp CMG3ESP, CMG40T, CMG-3T, Streckeisen STS2, Geotech KS2000, KS54000, MBB2, PBB) (*Neagoe et. al*, 2011). In June 2020, the Romanian strong motion network consisted of 163 stations (EpiSensor-2g full scale) of which 21 stations were deployed in the Bucharest area. Most of these accelerometers are collocated with the seismic stations. The common sampling rate of the data recorded by the most seismic RSN stations is 100 sps; however, several stations are sending 20-sps data.

In 2008, in the South-Eastern part of Romania near the Black Sea, a new and modern Observatory was opened at Eforie (EFOR) as back-up for the data acquisition and processing and as a monitoring center for Black Sea tsunamis. The station also includes equipment to measure the electromagnetic field and UV radiation.

To measure the ground motion deformation, a GPS network was developed in 2001. At the moment there are 29 measuring points. Data acquisition and real time transmission is carried out using commercial and professional/scientific programs such as: Gipsy Oasis II, Gipsy Oasis X, Bernese 5.2, GAMIT, MIDAS, Leica Geo Office, RTKlib, Leica VADASE and Leica SpiderQC v7.3. Data is sent to the NDC in standardized RINEX format and archived on a dedicated storage of 30 TB.

Between 1994 and 2002, a modern seismic three-component system, consisting of Quanterra 380 digitizer and three short-period sensors S13 (arranged along the three-dimensional axes), was deployed at the Muntele Rosu Observatory (MLR) in the framework of cooperation with the German Network (GEOFON). In 2004, the GEOFON equipment from MLR were relocated at TIRR station, which was permanently included in the GEOFON network in Romania.

In 1996, the MLR seismological station was included as an auxiliary station (AS081) into the International Monitoring System (IMS) coordinated by the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization). In 1999, supported by technical cooperation with the Government of Japan and technical assistance from the CTBTO, a major upgrade was carried out at MLR station: the existing equipment was replaced with a high-performance STS-2 broadband sensor and Quanterra 4120 data logger; a strong motion sensor (EpiSensor ES-T, FBA) was installed as well. The data is continuously recorded

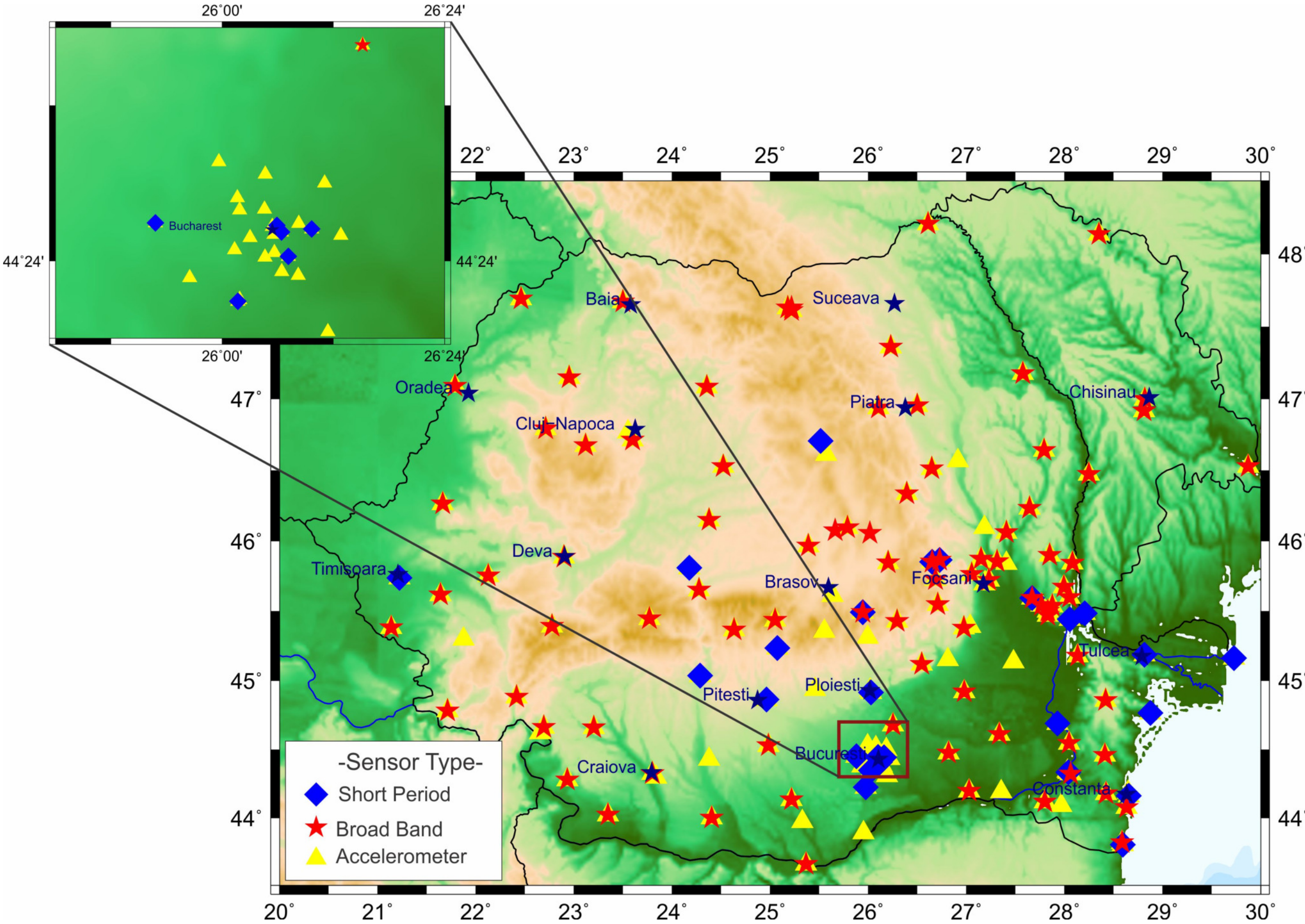

Figure 6.4: *The status of the Romanian Seismic Network in June 2020.*

Code	Location	Number of elements	Aperture km	Inter-element distance / m	Operation period
BURAR	Benea, Suceava County	10	4.5	500 – 2000	Jul 2002 – present
PLOR	Plostina, Vrancea County	7	2.5	250 – 1100	Oct 2007 – present

Table 6.1: *Set up of the two Romanian arrays.*

and transmitted in real-time to the NDC in Măgurele and IDC (International Data Center of CTBTO) in Vienna.

6.1.3 Seismic Arrays in Romania

From 2002, two seismic arrays have been deployed on Romanian territory (Figure 6.5) by the National Institute for Earth Physics (NIEP): BURAR (under cooperation with Air Force Technical Application Center AFTAC (USA) and PLOR. The main information about the arrays is given in Table 6.1.

The 10 seismometers of the BURAR array are located in boreholes of 30, 45 and 60 m depth. Nine sites (BUR01, BUR02, . . . , BUR09) are equipped with vertical 1-C SP GS21 (Geotech Instruments) instruments; the tenth site of the array (BUR31) is equipped with 3-C BB instrument: KS54000 (Geotech Instruments) (between 2002 and 2017) and CMG-40T (Guralp) (since August 2017).

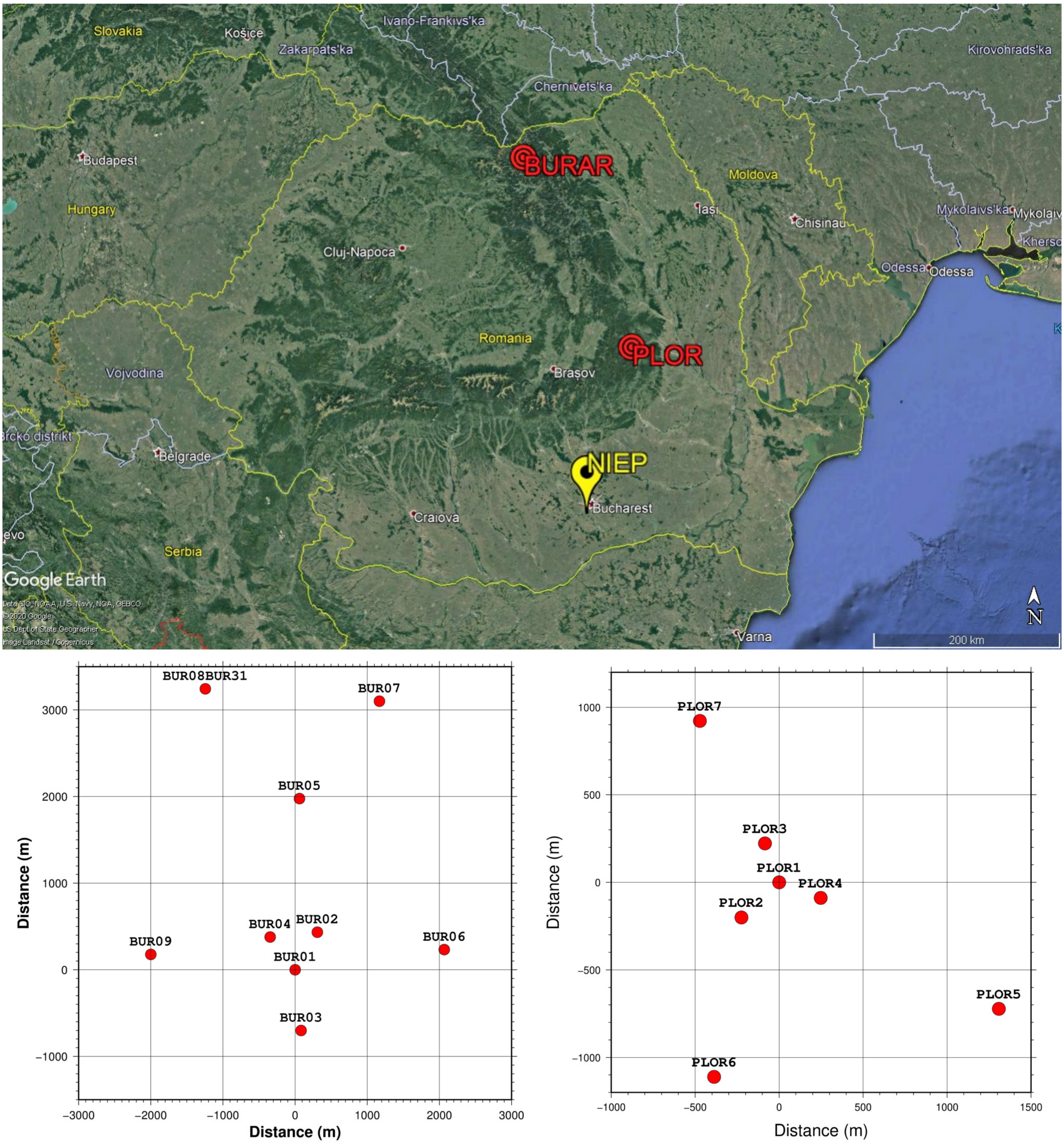

Figure 6.5: Top: *Geographical position of NIEP and the two seismic arrays deployed on Romanian territory.* Bottom left: *BURAR array.* Bottom right: *PLOR array.*

The 7 seismometers of the PLOR array are located in vaults of 3 m depth. Six sites (PLOR2, PLOR3, . . . , PLOR7) are equipped with 3-C BB CGM40T (Guralp) instruments and one (PLOR1) - with 3-C BB STS-2 (Streckeisen) seismometer. The seismic array will be upgraded with high quality velocity sensors to ensure we will obtain good results for local seismicity.

The data are continuously recorded and transmitted in real-time to the NIEP Data Centre (in Măgurele), where they are processed and analysed using advanced array techniques to enhance valuable signals from seismograms: such as beamforming (e.g., *Capon et al.*, 1967) and frequency-wavenumber (f-k) analysis (e.g. *Capon*, 1969).

During their operation, BURAR and PLOR seismic arrays have proven to be sensitive stations providing good monitoring coverage of Romania's territory for both regional and distant seismicity.

Since 2009 (PLOR) and 2016 (BURAR), the two seismic arrays have been colocated with infrasonic stations.

6.1.4 Data Acquisition, Event Detection and Processing

The real-time data arrives in Măgurele and are initially processed automatically, using Antelope software (installed in 2001 at NIEP). Data from the 155 RSN stations and the 104 stations from countries with which we have signed collaboration agreements on data exchange (Italy, Greece, Turkey, Bulgaria, Serbia, Ukraine, Poland, Germany, France, Holland, USA, Austria and Switzerland) are provided through a seedlink server.

The Antelope software (`http://www.brtt.com/software.html`) is running on three servers for data acquisition as well as automatic and real-time data processing, data distribution and seismic data archiving. One server works as a principal unit and the other two are working as back-up units. A block diagram describing the data processing flow is shown in Figure 6.6.

The **slink2orb** program is used to transfer data packets from a seedlink server to Antelope real-time systems. The automatic data processing is performed by Antelope using **orbdetect**, **orbassoc** and **orbevproc** programmes. The STA/LTA (Short Time Average over Long Time Average) trigger algorithm is applied by **orbdetect** on the real time data for each seismic channel on different frequency bands. The detection information is stored in real time in the Antelope database. The channel specification, frequency bands, filters, STA/LTA time windows, and detection threshold values are all user configurable. The detections obtained from **orbdetect** are transmitted to the **orbassoc** program which has the role of verifying the number of detections in a minimum time window configured by the user to decide if a seismic event was detected. If the number of detections meets the specified conditions, the **orbassoc** program will associate phases in correlation with the velocity model specific to the monitored areas and the location of the seismic event is obtained.

The real time Richter magnitude is computed using the **orbevproc** program based on the maximum amplitude read on the components of each station. The M_L magnitude of the event is given by the average of the magnitudes obtained for each station used in the location procedure. From 2016 for the M_L real time calculation events which occurred on Romanian territory the Antelope software uses the following formulas:

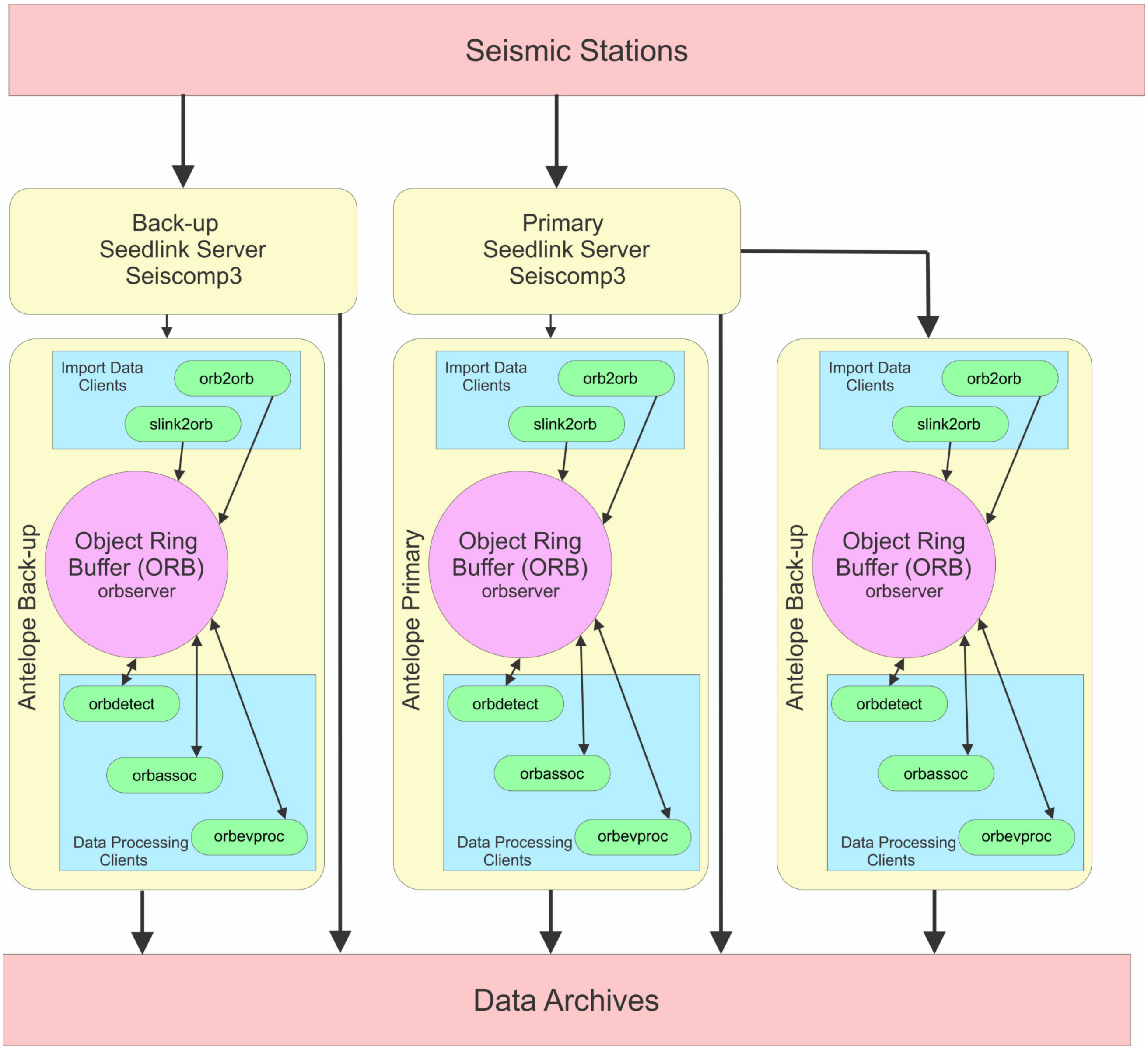

Figure 6.6: *Data processing flow chart. See text for explanation on algorithms.*

- for crustal events:
$$M_L = \log_{10} A - \log_{10} A_0(\Delta),$$
- for intermediate-depth events (h $\geq$ 60 km):
$$M_L = \log_{10} A - \log_{10} A_0(\Delta) + 2\,(4.5 - \log_{10} A - \log_{10} A_0(\Delta))/4.5 \qquad \text{if } M_L \leq 4.5$$
$$M_L = \log_{10} A - \log_{10} A_0(\Delta) \qquad \text{if } M_L > 4.5,$$

  where M_L is the local magnitude, A the maximum Wood-Anderson amplitude (mm) and A_0 the maximum amplitude at distance $|delta$ for standard (zero) earthquake (which has an amplitude of 0.001 mm at 100 km).

For earthquakes with $M_L \geq 3.0$, the moment magnitude (M_W) is also computed using acceleration waveforms and the calculation program developed by *Gallo et al.* (2014). The earthquake mechanism and the moment tensor are also determined.

The routine processing includes manual phase identification and hypocenter location using Antelope software. The velocity model used for locating all events (local, regional and teleseismic) is IASP91 (*Kennett and Engdahl*, 1991). For local and regional events, the P and S phases are picked at all stations where they can be clearly identified. At teleseismic distances, only the P phase is picked. For local and regional events up to 20 degrees from the geographical centre of Romania M_L is computed. For events that occurred at more than 20 degrees, mb magnitude is computed. In all cases, the magnitude is calculated based on the value of the maximum amplitude.

At the end of each day, a seismic phase bulletin is issued containing all the phases of the identified, associated and unassociated events. This bulletin and the bulletin containing the locations of the events that occurred on Romanian territory (ROMPLUS, see Section 6.1.6) are reviewed weekly and sent to international data centres. In the first days of each month, the bulletins of the previous month are produced. The bulletins contain all identified phases and locations of local events including the events that occurred in the border area.

Using the records of broadband sensors and accelerometers, information required by seismic engineering is automatically calculated, such as: PGA (Peak Ground Acceleration), PGV (Peak Ground Velocity), SA (Spectral Acceleration), IA (Arias Intensity), CAV (Cumulative Absolute Velocity), IMSK (Improved macroseismic Scale). This information is then used by programs such as: SHAKEMAP, SELENA and PAGER to produce intensity maps and to inform the public, authorities, emergency relief and media.

In case of an earthquake with magnitude $M_L \geq 3.0$ occurring on Romanian territory, Antelope software automatically produces a Shakemap. For local events with local magnitude greater than 4.0 the alerting system (EWS) sends an e-mail and SMS messages to dedicated recipients. All the Antelope products (near real-time earthquake locations, Shakemaps, seismicity maps for local earthquakes) are available on the NIEP website (`http://www.infp.ro`). In case of a felt earthquake, people can fill out the "Did you feel it?" form on the NIEP website. All the collected information is sent to the local authorities, used for intensity maps and for research studies.

From 2008, SeisComP3 (`http://www.seiscomp3.org/`), another automatic system, has been running in parallel with Antelope. It performs data acquisition, data quality control, real-time data processing and

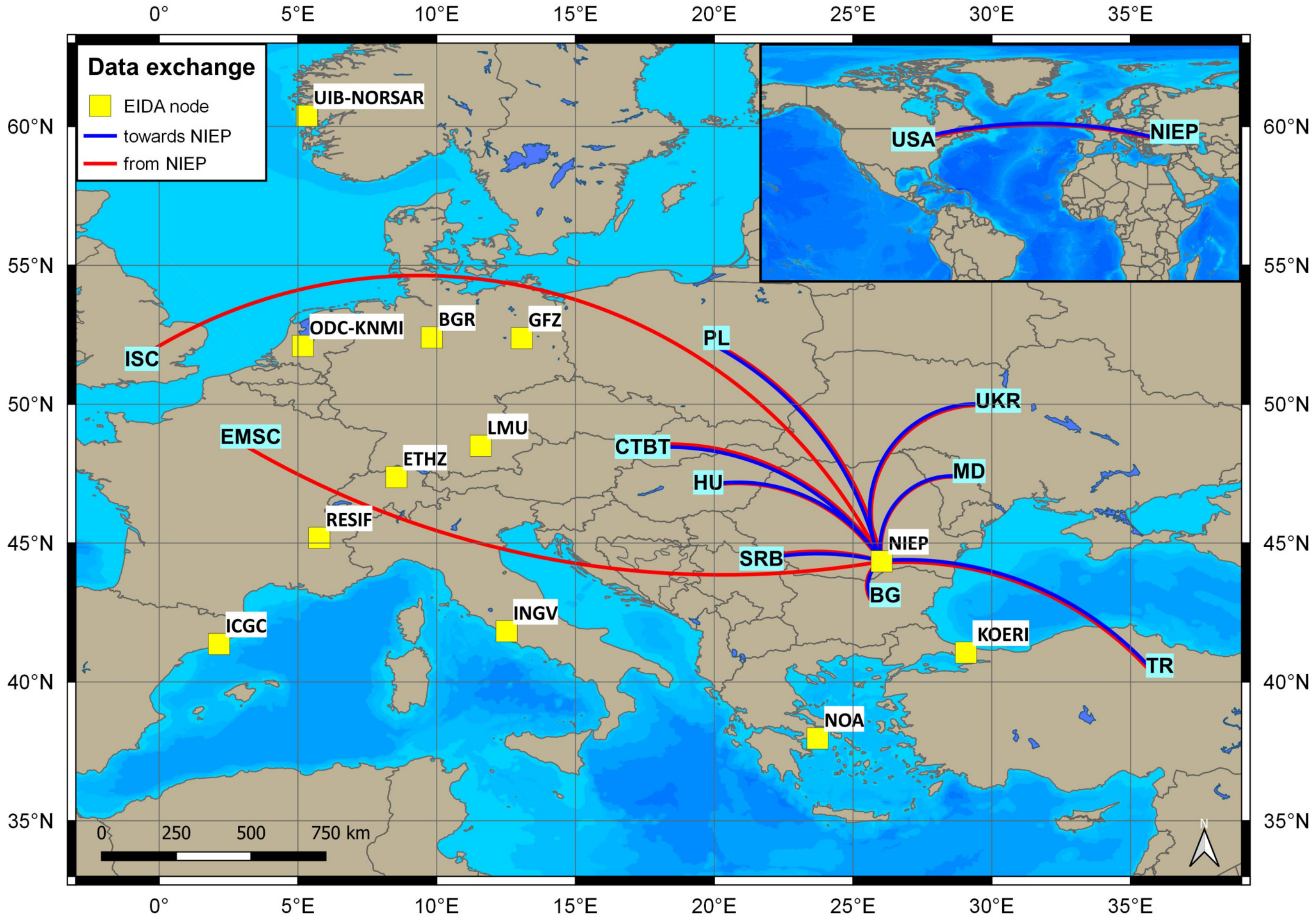

Figure 6.7: *Data exchange ensured by RSN and NDC.*

exchange, monitoring of the network state-of-health, automatic and interactive detection and location of events, archiving and distribution of waveforms. SeisComP3 provides a data transmission protocol (SeedLink) used at NIEP for real-time data transmission from seismic stations in Romania to the Data Centre in Măgurele.

6.1.5 Data Availability and Exchange

The RSN and NDC ensure the global real-time data and seismic bulletin exchange with national (Republic of Moldova, Bulgaria, Hungary, Serbia, Ukraine, Poland) and international data centres (International Seismological Centre (agency code BUC), International Data Centre of CTBTO, European Mediterranean Seismological Centre) and seismological organizations (ORFEUS, IRIS) (Figure 6.7).

RSN/NDC shares real-time waveform data through EIDA (European Integrated Data Archive). NIEP has been an EIDA primary node since 2014.

Waveforms from seismic stations located in Romania, Republic of Moldova, Bulgaria and Ukraine are included in the EIDA regional node hosted by the National Institute for Earth Physics. Currently, NIEP has a seismic data archive of around 25 TB.

Data is accessible through the FDSN Web Services:

- FDSNWS - Dataselect (miniSEED): `http://eida-sc3.infp.ro/fdsnws/dataselect/1/`
- FDSNWS Station (station metadata): `http://eida-sc3.infp.ro/fdsnws/station/1/`

Another service provided by NIEP is the routing service. The routing service is a web service that routes requests for different services between EIDA Nodes. Different networks will be routed to specific data centres depending on the data request. Routing service can be accessed at `http://eida-sc3.infp.ro/eidaws/routing/1/`.

NIEP also provides a waveform metadata web service. WF Catalogue is a web service that provides detailed information on the content of waveform data including quality control parameters. The WF Catalogue can be accessed at `http://eida-sc3.infp.ro/eidaws/wfcatalog/1/`.

6.1.6 Seismic Events Catalogue

Comprising the seismic events located on Romanian territory and inside the border areas, the Romania earthquakes catalogue (ROMPLUS) is built by compiled data from previous catalogues and new locations. The catalogue was first published in 1999 (*Oncescu et al.*, 1999) and since then has been continuously updated (`http://www.infp.ro`). It includes historic earthquakes (starting with 984) located using historical documents (manuscripts, newspaper notes, notes from the archives of churches and monasteries). After 1900, the events recorded by the first installed seismometers were located based on phases read on seismograms and, in the case of larger earthquakes, phases from national and international centres were added. Following the increase in number of stations that resulted in a superior coverage of the Romanian territory, and the upgrading of the instrumentation, the number of detected and localized events increased significantly (Figure 6.8). As a result, the completeness of the catalogue varies over time and space.

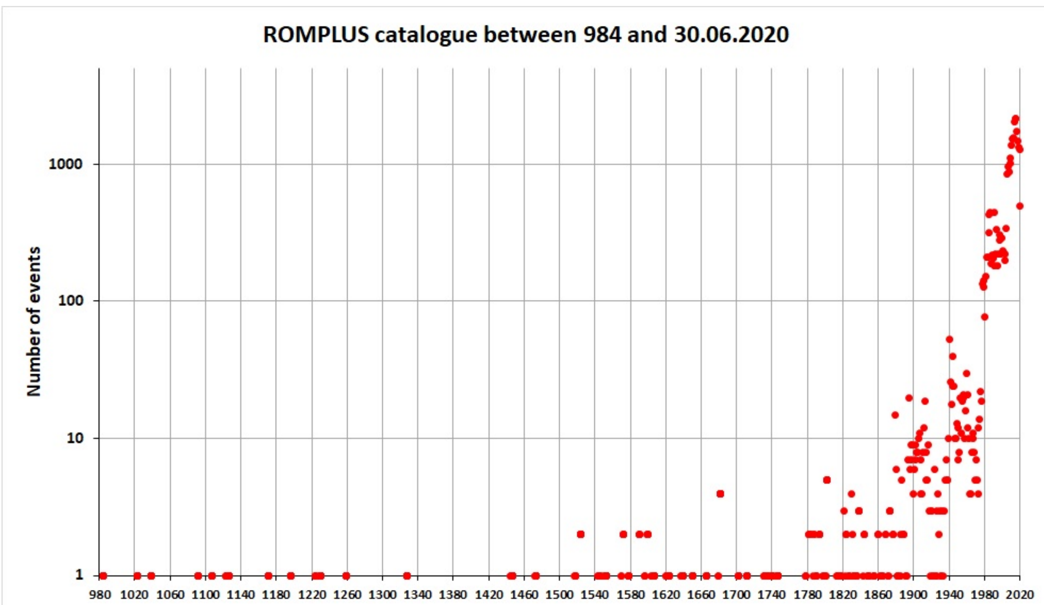

Figure 6.8: *Exponential increase of localized events (ROMPLUS catalogue) with the development of the National Seismic Network.*

Between 1980 and the beginning of 2014, the (re)locations were computed using the HYPOPLUS program (*Oncescu et al.*, 1996), and a 1-D velocity model. Since 2014, the Antelope software has been used for primary and revised event location using the IASP91 velocity model. Currently, the magnitude M_L computed with the Antelope program is converted to moment magnitude (M_W) on the basis of some conversion relations obtained for the earthquakes produced on Romanian territory. A database which will supplement the information in the catalogue with information about the type of event (earthquake, explosion, supposed explosion) and references to studies of events in the catalogue and information on other existing data about events (macroseismic information, shakemaps, etc.) is now under construction.

Acknowledgements

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References

Capon J., R.J. Greenfield and R.T. Lacoss (1967), Design of seismic arrays for efficient on-line beamforming, *Technical note 1967-26*, Massachusetts Institute of Technology, Lincoln Laboratory.

Capon J. (1969), High-resolution frequency-wavenumber spectrum analysis, *Proc. IEEE*, *57*(8), 1408–1418.

Constantinescu, L., P. Constantinescu, I. Cornea and V. Lăzărescu (1976), Recent seismic information on the lithosphere in Romania, *Rev. Roum. Géol., Géophys., Géogr.*, *Ser Géophys. 20*, 33–40.

Neagoe, C., L. M. Manea and C. Ionescu (2011), Romanian Complex Data Center for Dense Seismic network, *Annals of Geophysics*, *54*(1), https://doi.org/10.4401/ag-4809.

Gallo, A., G. Costa and P. Suhadolc (2014), Near real-time automatic moment magnitude estimation, *Bull. Earthq. Eng.*, *12*(1), 185–202, https://doi.org/10.1007/s10518-013-9565-x.

Kennett, B.L.N. and E.R. Engdahl (1991), Travel times for global earthquake location and phase association, *Geophys. J. Int.*, *105*, 429–465, https://doi.org/10.17611/DP/9991809.

Oncescu, M.C., M. Rizescu and K.P Bonjer (1996), SAPS – an automated and networked seismological acquisition and processing system, *Comput Geosci*, *22*(1), 89-–97, https://doi.org/10.1016/0098-3004(95)00060-7.

Oncescu M. C., V. Marza, M. Rizescu and M. Popa (1999), The Romanian Earthquakes Catalogue, 984-1997. In: F. Wenzel, D. Lungu and O. Novak, (Eds.) Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation, *Advances in Natural and Technological Hazards Research*, *11*, Springer, Dordrecht, https://doi.org/10.1007/978-94-011-4748-4_4.

Wenzel, F., F.P. Lorenz, B. Sperner and M.C. Oncescu (1999), Seismotectonics of the Romanian Vrancea area. In: F. Wenzel, D. Lungu and O. Novak, (Eds.) Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation, *Advances in Natural and Technological Hazards Research*, *11*, Springer, Dordrecht, https://doi.org/10.1007/978-94-011-4748-4_2.