ISSN 0747-9239, Seismic Instruments, 2022, Vol. 58, Suppl. 2, pp. S281–S290. © Allerton Press, Inc., 2022.
Russian Text © The Author(s), 2022, published in Seismicheskie Pribory, 2022, Vol. 58, No. 4, pp. 130–143.

Assessment of the Recording Capabilities of the Kolba Seismic Station for Seismic Monitoring in the Western Sector of the Russian Arctic

G. N. Antonovskaya[a, *], E. R. Morozova[a], Ya. V. Konechnaya[b], and K. B. Danilov[a]

[a] *N. Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences, Arkhangelsk, 163020 Russia*

[b] *Federal Research Center "United Geophysical Survey of the Russian Academy of Science," Obninsk, Kaluga oblast, 249035 Russia*

**e-mail: essm.ras@gmail.com*

Received August 5, 2022; revised September 27, 2022; accepted October 3, 2022

Abstract—The Kolba permanent seismic station was installed in 2020 at the Kolba geophysical station (affiliated with the Northern Territorial Administration for Hydrometeorology and Environmental Monitoring), near the settlement of Dikson, Krasnoyarsk krai, in order to increase the sensitivity of the Arkhangelsk Seismic Network (affiliated with the N. Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences), which carries out seismic monitoring in the Barents–Kara region and adjacent areas. For regional earthquakes in the European sector of the Arctic, the representative magnitude was determined at $M_{L\mathrm{rep}} = 3.4$. The Kolba seismic station records local events of different nature with magnitudes from 0.8 to 1.7. The dependence of the number of revealed earthquakes on the level of microseismic noise is revealed.

Keywords: Western sector of the Russian Arctic, seismic station, microseismic noise level, earthquakes, technogenic events, local magnitude

DOI: 10.3103/S0747923922080035

INTRODUCTION

Monitoring of natural processes is an inherent part of not only fundamental research, but also effective development of new regions. Development of monitoring systems to observe the current situation and forecast emergencies in the Arctic zone is one of the tasks from such documents as the *Unified Plan of Actions to Implement the Basic Principles of State Policy of the Russian Federation in the Arctic for the Period until 2035* and *Development Strategy for the Arctic Zone of the Russian Federation and National Security Policy for the Period until 2035*, adopted by the Russian Federation Government on April 15, 2021 as no. 996-r. One of the most serious causes giving rise to emergencies is earthquakes. In order to monitor seismicity, Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences (hereinafter, FECIAR UrB RAS) deals with expansion of the seismological network in the western sector of the Russian Arctic. Since 2010, the Arkhangelsk Seismic Network of FECIAR UrB RAS has included the following stations (Fig. 1):

(1) Amderma (2010), installed in the area of the eponymous settlement in the Nenets Autonomous Okrug;

(2) Zemlya Frantsa-Iosifa (Franz Josef Land, 2011) and Omega (2015), installed on Alexandra Land, Franz Josef Land;

(3) Severnaya Zemlya (2016), installed at the Cape Baranov Ice Base permanent research station on Bolshevik Island, Severnaya Zemlya.

These seismic stations enable observations in the area extending to 125° E and also reduce the representative magnitude of recorded seismic events for the western sector of the Russian Arctic down to $M_{\mathrm{rep}} = 3.5$ (Antonovskaya et al., 2022). Owing to installment of these seismic stations, it has become possible to obtain novel data on tectonic activity and deep structure (down to 300 km) of the western sector of the Russian Arctic and to establish the relationships between geodynamics of mid-ocean ridges and manifestations of intraplatform earthquakes (Antonovskaya et al., 2020, 2021; Morozov et al., 2020, 2021).

The Arctic stations of FECIAR UrB RAS regularly record low-magnitude earthquakes ($M_L < 2.5$), although large distances between stations (more than 1000 km) complicates the location of these earthquakes. Such earthquakes are usually recorded by two stations; hence, they cannot be included in any seismological catalog. As a result, a considerable number of earthquakes in the Barents–Kara region do not fall

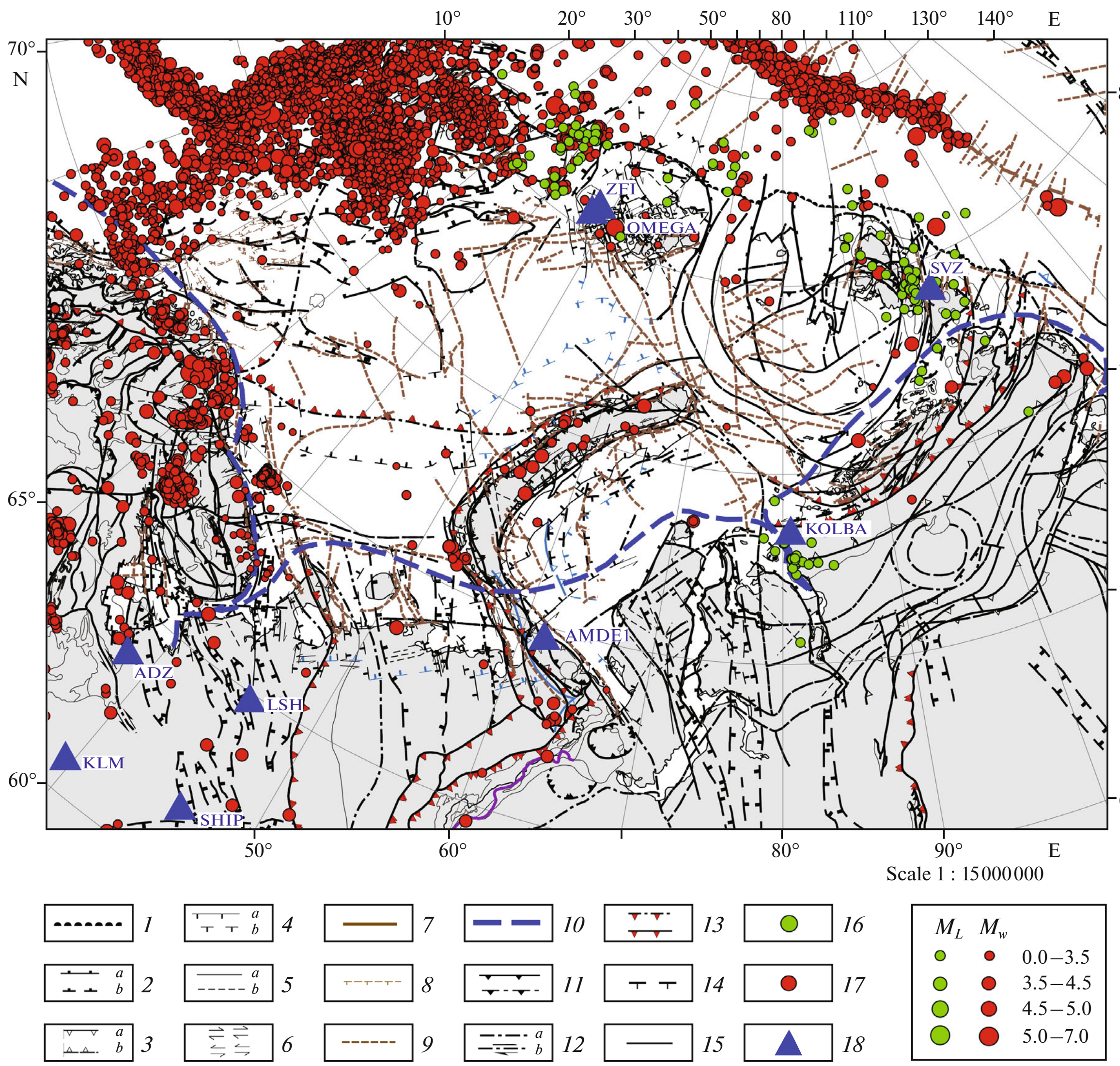

Fig. 1. Seismicity of western sector of Russian Arctic for 1980–2020: (*1*) shelf margin; (*2–5*) recent faults, after (*Atlas*..., 2004): (*a*) confirmed, (*b*) inferred, (*2*) normal faults (hatching marks footwall); (*3*) reverse faults (triangles mark hanging wall), (*4*) faults with uncertain kinematics (hatching marks footwall); (*5*) faults with no identified slip; (*6*) slip directions for strike-slip faults; (*7–9*) faults, after (Spencer et al., 2011): (*7*) active spreading center, (*8*) normal faults, (*9*) unclassified faults; (*10*) Northern Sea Route; (*11–15*) faults, after (Pubellier et al., 2018): (*11*) thrusts and reverse faults, (*12*) transpressional fault (arrow shows slip direction), (*13*) deformation front for orogens, (*14*) listric normal fault, (*15*) unclassified faults; (*16*) events recorded by one station; (*17*) earthquakes from seismic catalog; (*18*) stations of Arkhangelsk Seismic Network, FECIAR UrB RAS.

within the data set (Fig. 1). The stations of the Arkhangelsk Seismic Network of FECIAR UrB RAS annually record 1000–1200 seismic events, of which only 300–400 are included in seismic catalogs. Figure 1 shows the spatial distribution of seismicity in the Barents–Kara region for 1980–2020. The main seismicity data were taken from the catalog of the International Seismological Centre (ISC) (International..., 2022), and supplemented with the FECIAR UrB RAS catalog for 2012–2020 (including seismic events recorded by one station). Since 2014, FECIAR UrB RAS has been a partner of the ISC and participates in global seismic monitoring (International ..., 2022).

With respect to the above, an increase in the density of seismic networks in the Russian Arctic is a topical problem. In the present study, we analyze the results of 1.5 years of operation of the Kolba seismic station since its commissioning.

MAIN INFORMATION ON THE KOLBA SEISMIC STATION

The Kolba seismic station was incorporated into the Arkhangelsk Seismic Network, FECIAR UrB RAS since its commissioning on October 11, 2020. The station was installed in the area of the urban-type settlement of Dikson, Taimyr Dolgan–Nenets District of Krasnoyarsk krai, at the Khodov Kolba geophysical station, affiliated with the Northern Territorial Administration for Hydrometeorology and Environmental Monitoring (Fig. 1). The international and regional code is KOLBA; coordinates $\varphi = 73.529°$ N, $\lambda = 80.701°$ E, $h = 11$ m. The initial data are represented by a continuous seismic record in the frequency band from 0.033 to 25 Hz with sampling rate of 50 samplings/s.

The Kolba seismic station is equipped with highly sensitive instruments manufactured by the Nanometrics company (Canada): a TC-120s broadband seismometer and Centaur device. The data are transferred by the SeedLink protocol via the Internet to the server of the Laboratory of Seismology, FECIAR UrB RAS.

DATA AND PROCESSING METHODS

Since the Kolba seismic station records different types of seismic events (earthquakes, icequakes, technogenic events), at the primary analysis stage, the bandpass filter should be accurately adjusted for each type. Sometimes it becomes possible to identify an earthquake in the record by using the catalogs from such international agencies as the United States Geological Survey (USGS) (US Geological Survey, 2022), the Norwegian Seismic Network (NORSAR) (NORSAR..., 2022), and Unified Geophysical Survey of the Russian Academy of Sciences (GS RAS) (Federal Research Center..., 2022). However, a large number of icequakes recorded in winter complicates identification of regional and local earthquakes.

Seismic data are processed in the WSG (Windows Seismic Grapher) software package, developed jointly by GS RAS and SPA Geotekh (Akimov and Krasilov, 2020). Initial processing entails analysis of the initial record in order to reveal regional and local seismic events with subsequent documentation of information about them in the station bulletin. Then the data from the Kolba seismic station are involved in joint data processing for the entire Arkhangelsk Seismic Network, with the data of initial records of seismic stations from international and regional seismological agencies (GEOFON, 2022; IRIS, 2022). Processing is performed based on the data from at least three stations.

The compiled seismic bulletins and catalogs of the Arkhangelsk Seismic Network are regularly sent to the ISC (International..., 2022) and GS RAS (Morozov et al., 2021), where they are involved in earthquake processing at a global level. Monthly seismicity maps are published on the website of FECIAR UrB RAS (Unique Research Facility Arkhangelsk..., 2022). In summarized processing they apply the BARENTS regional travel-time curve (Kremenetskaya et al., 2001) and local magnitude M_L scale for the western part of the Eurasian Arctic (Morozov et al., 2020).

The events recorded only by the KOLBA seismic station and not revealed in records of other stations are processed separately in the EventLocator program (Software compelx EL, 2022). Epicenters are determined from calculated epicentral distances and backazimuts. The error in locating seismic events using this method is estimated at ±17 km for an epicentral distance of 100 km and focal depth of 5 km. It is an undoubtedly less reliable location method, but it allows insight into the epicentral distribution of these events. To assess the quality of station records, we have analyzed the level of microseismic noise by plotting power spectra relative to Peterson's models (Peterson, 1993) in the MicroNoize program (Dyagilev, 2012).

RESULTS AND DISCUSSION

Miscroseismic Noise

The Kolba station is located far from significant technogenic noise sources (more than 6 km). Analysis of continuous seismic records has shown that no technogenic noise is superimposed on waveforms. In the entire frequency band, the level of ambient seismic noise at the Kolba seismic station tends to the lower limit of Peterson's models (Peterson, 1993). Figure 2 shows the characteristic seasonal variations in the diurnal power spectra of microseismic noise for 2021.

Clearly, in winter–spring, the ambient seismic noise level tends to the lower limit of Peterson's models (NLNM curve), giving grounds to assess the recording capabilities of the station as potentially high. In summer, the ambient seismic noise level in the entire frequency range increases, but nevertheless remains within the average values with respect to Peterson's models. This is likely related to exposure of the land surface after ice thawing and to the more intensive technogenic activity at this time. The peak marine microseisms shift towards higher frequencies (up to 0.5 Hz) in August–September, and this can be linked to the fact that the sea becomes clear of ice. Similar processes have a negative influence not only on the number of recorded events, but also on the quality of isolating their waves. In October, when nearby rivers and the sea are freezing and snow cover begins to form, the level of ambient seismic noise starts to drop, first of all in the frequency range from 2 Hz or higher, which corresponds to the frequency band for distinguishing regional (at closer distances) and local events. A high level and broad range of marine microseisms is also observed, which complicates the use of a classical filter (0.7–1.4 Hz) for teleseismic events.

Figure 3 shows the dependence of the number of regional and local earthquakes on the microseismic power spectra. The plot presents monthly power spectra values at frequencies of 2 and 7 Hz, which correspond to the average values of bands in which regional and local events are recorded. The ambient seismic noise level at 2 Hz increases from May to October (six months), while this level at 7 Hz takes increases over

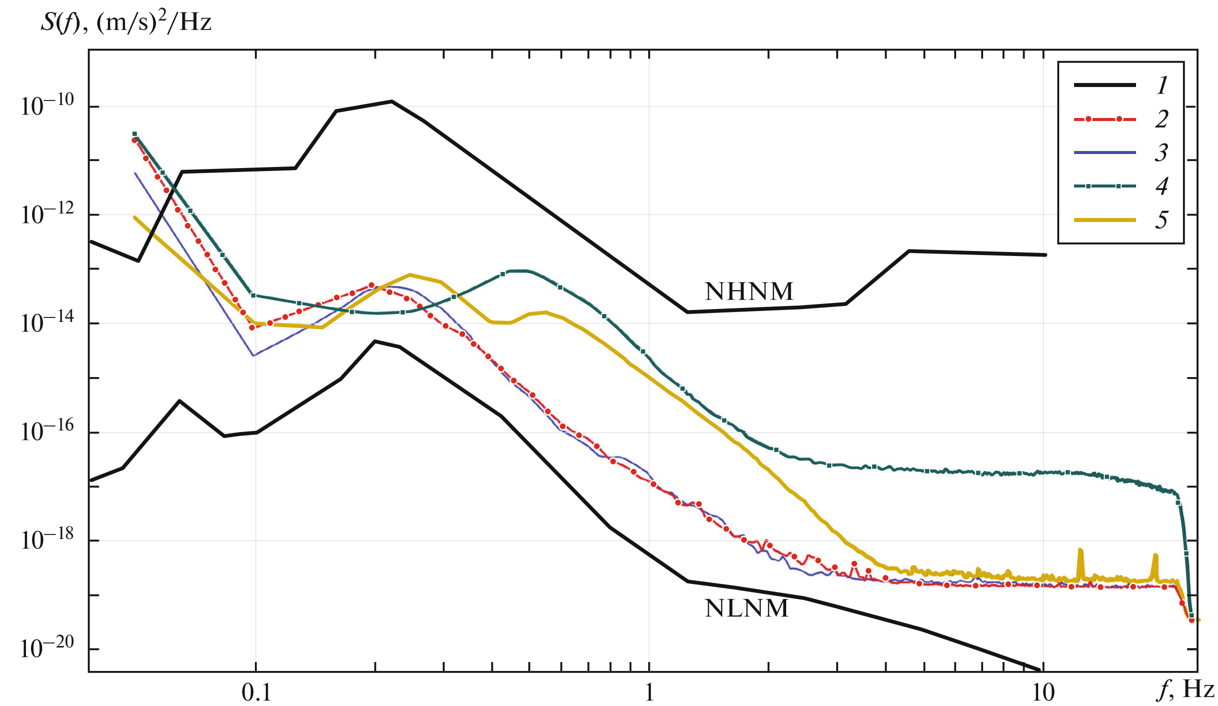

Fig. 2. Characteristic diurnal power spectra from BHZ broadband channel for microseismic noise level at Kolba seismic station versus Peterson's models (Peterson, 1993): (*1*) lower (NLNM) and higher (NHNM) limits of Peterson's models; (*2*–*5*) diurnal power spectra for various dates corresponding to various seasons: (*2*) January 15, 2021; (*3*) April 15, 2021; (*4*) August 15, 2021; (*5*) October 15, 2021.

months (from July to September). Figure 3 shows than a increase in the ambient seismic noise level by two orders of magnitude causes a three- to fivefold decrease in the number of recorded earthquakes.

Regional Earthquakes

For the period from October 2020 to December 2021, the Kolba seismic station recorded 288 regional seismic events (at distances from 200 to 2000 km) of various types, i.e., natural (earthquakes) and technogenic (related to industrial activity).

The events occurring at epicentral distances of about 500 km from the Kolba station can be distinguished as a separate group: their local magnitudes M_L fall within the range of 2.3–3.0. These events are identified using 4–8 Hz filters and have mutually similar waveforms: a weaker *P*-wave arrival and more reliable *S*-wave arrival. Figure 4 shows examples of the waveforms and processing results. The epicentral circle always "passes" near the city of Norilsk.

In order to locate and reveal the nature of such events, we have acquired the data on a October 16, 2020 earthquake from the NRIK station (because there were other seismic stations at distances less than 500 km from the Kolba one, while the operating stations of other seismic networks had not recorded this event). Joint processing at two stations allowed us to locate this event in the area of a mining enterprise; therefore, this is very likely a technogenic event. Despite the fact that processing was done by only two stations, the location was determined, in our opinion, quite accurately, owing to reliable determination of the backazimuts from the NRIK station records. In Fig. 4b, the located event is marked with red circle.

Events with similar waveforms should be processed with particular care, because any deviations from the standard record and changes in epicentral distances may indicate a different nature of event and suggest that an event is unrelated to industrial activity near Norilsk. In such a case, more thorough processing of the event record is required, including analysis of records in all available filters, the maximum possible number of stations in order to provide an exact epicentral location, reliable identification of seismic phases in records, and, whenever possible, estimation of error ellipses.

The main objective of installation of the Kolba seismic station was to record earthquakes in the Arctic. Figure 5 shows the map of earthquakes recorded by the KOLBA seismic station from October 2020 to December 2021 (139 events in total) and located with joint processing by other Arctic seismic stations. The earthquake distribution (Fig. 5) shows that the Kolba seismic station records seismic events occurring in the main seismically active zones of the Arctic: the Mona,

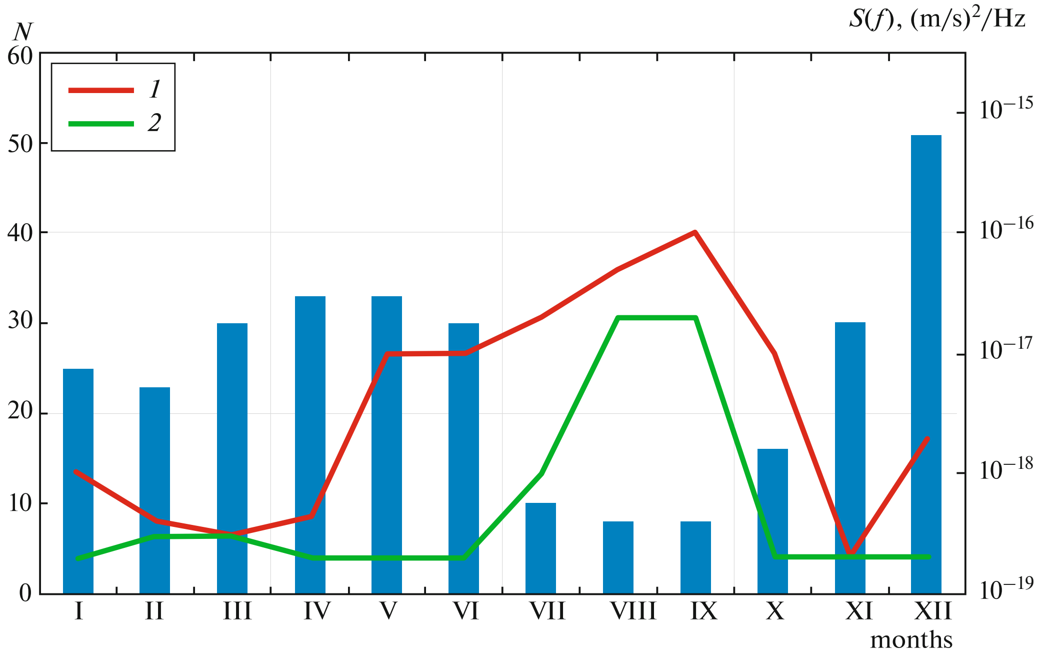

Fig. 3. Plot showing distributions of regional and local seismic events N and power spectra values for frequencies of (*1*) 2 and (*2*) 7 Hz (monthly distribution for 2021).

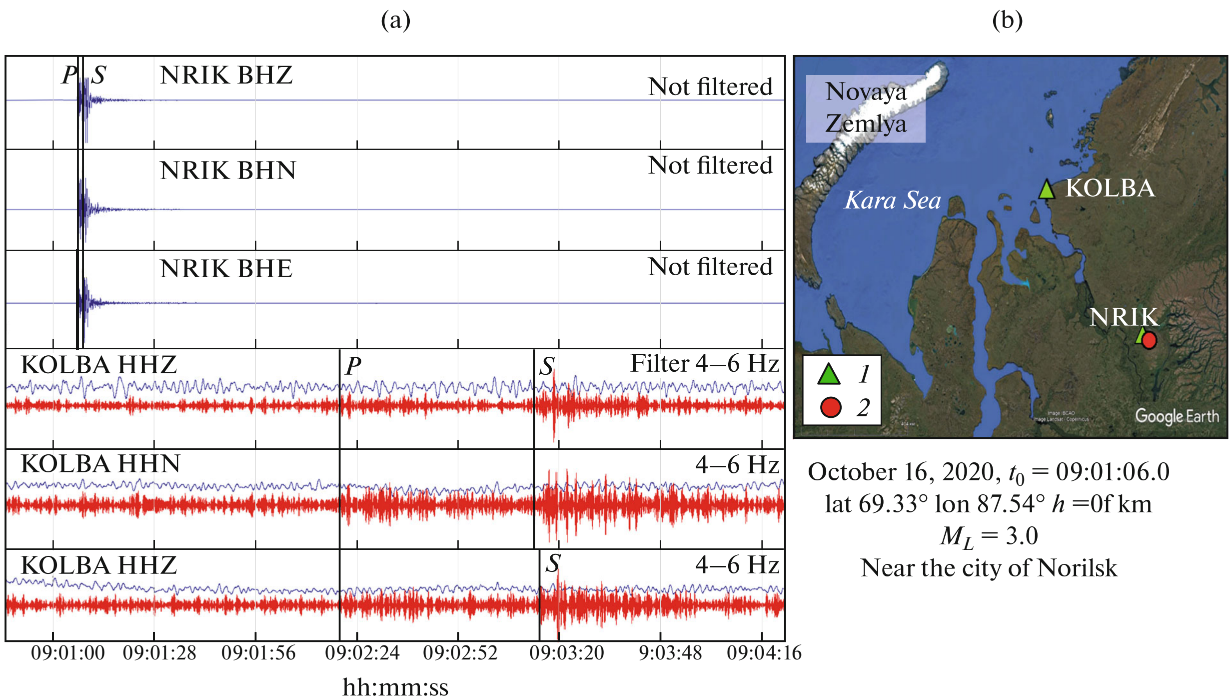

Fig. 4. Regional technogenic seismic event of October 16, 2020, recorded by Kolba seismic station: (a) records from NRIK and KOLBA stations; (b) calculated epicentral location: (*1*) seismic stations; (*2*) epicenter.

Knipovich, and Gakkel ridges. The strongest of these earthquakes (at least 4.0 in magnitude) have been documented in catalogs of such international agencies as NORSAR (NORSAR..., 2022), USGS (US Geological Survey, 2022), and GS RAS (Federal Research Center..., 2022); low-magnitude events are mostly absent in these catalogs. In addition, the Kolba station recorded several earthquakes on the arch Novaya Zemlya, on the Taimyr Peninsula, and in the Lena River estuary, although weak seismicity was almost not

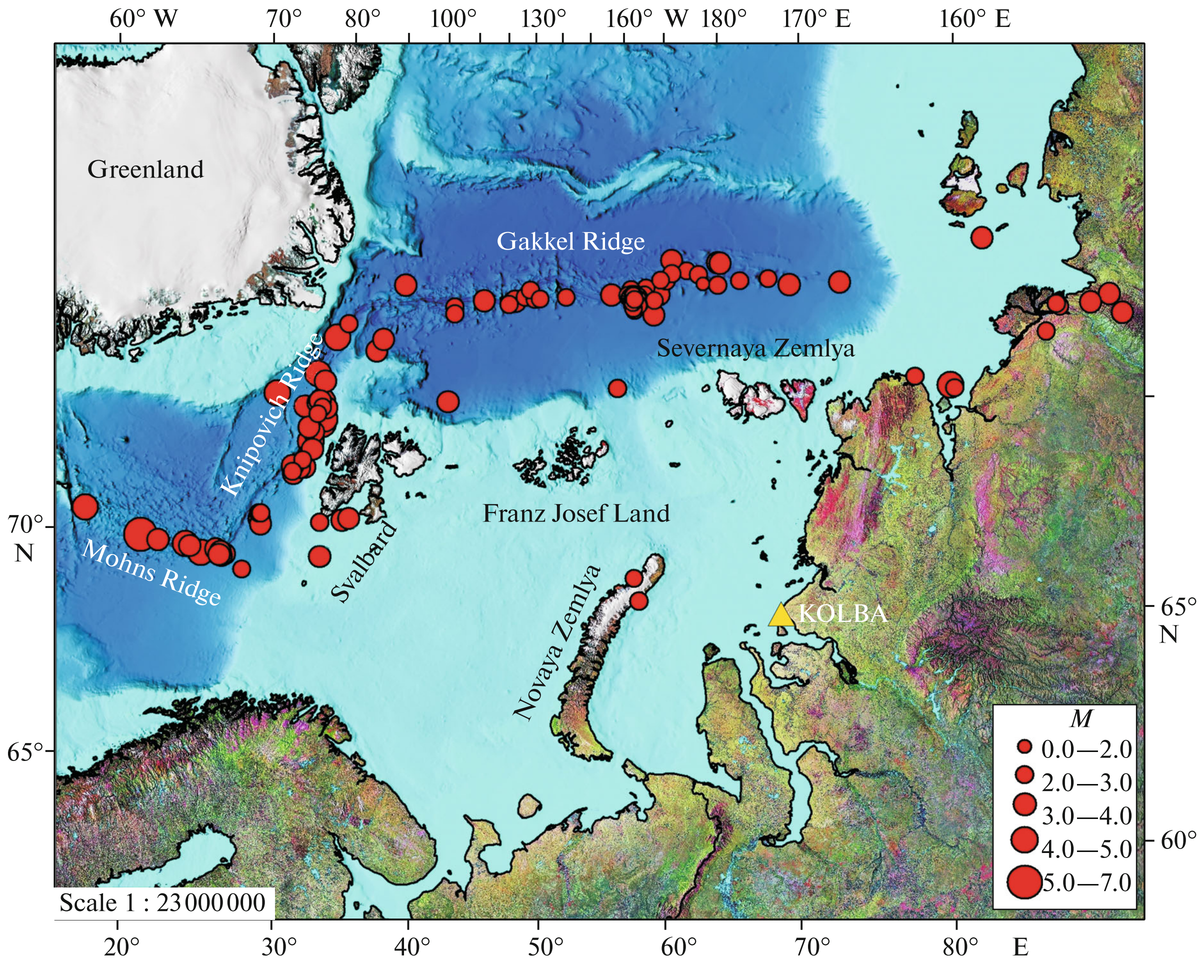

Fig. 5. Map showing distribution of earthquakes that occurred in Arctic from October 2020 to December 2021 and recorded by Kolba seismic station.

recorded for the northern margin of the Barents–Kara shelf due to its remoteness.

From the seismic catalog, we obtained the cumulative recurrence plot and quantitatively estimated the representative magnitude for the Kolba seismic station, $M_{L\text{rep}} = 3.4$, which is consistent with the representative magnitude for the Arkhangelsk Seismic Network on the whole (Antonovskaya et al., 2022).

Most regional earthquakes recorded by the Kolba station are not presented in international catalogs or in catalogs compiled by the GS RAS, due to the small magnitudes of these earthquakes. An example of location of such an earthquake is shown in Fig. 6. In the records of the Kolba seismic station, a regional earthquake with an epicentral distance of 1600 km was identified; this earthquake is not listed in seismic catalogs, although it was also recorded by the Omega (OMEGA) seismic station of the Arkhangelsk Seismic Network. To determine the epicentral location of this earthquake, we additionally used waveforms from the SPA0 station in Norway. Based on the records from these three stations, the earthquake was located on the western Gakkel Ridge (*1* in Fig. 6b). The local magnitude M_L was determined as 4.0 based on the data from OMEGA; $m_b = 4.2$, according to data from the Kolba seismic station.

Local Earthquakes

For the period from October 2020 to April 2022, the Kolba seismic station recorded 80 local seismic events in the magnitude range $M_L = 0.6–2.4$. Similarly to regional seismic events, local events are of either natural or technogenic origin.

In the vicinity of the port of Bukhta Sever, where construction works had began in summer 2021, 14 technogenic earthquakes were distinguished with magnitudes from 0.8 to 1.7. In order to identify seismic events, a 6–10 Hz filter was applied. Note that other Russian seismic stations did not record these earthquakes. Figure 7 shows examples of the corresponding waveforms.

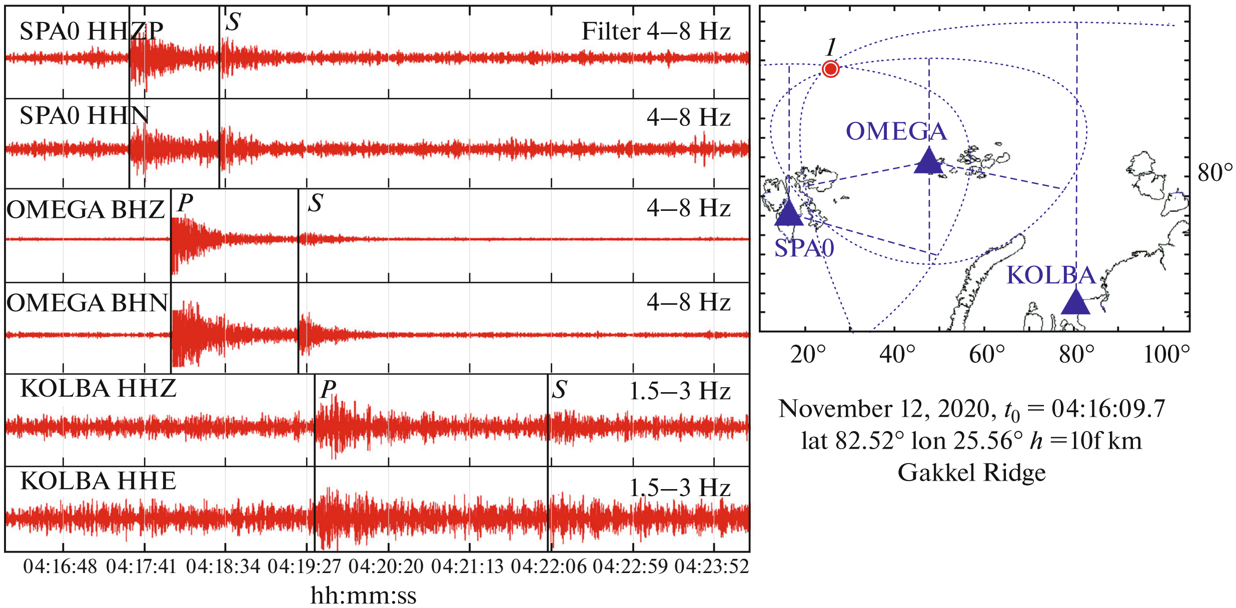

Fig. 6. (a) Waveforms and (b) fragment of processed record of earthquake that occurred in Gakkel Ridge area on November 12, 2020: (*1*) calculated earthquake location.

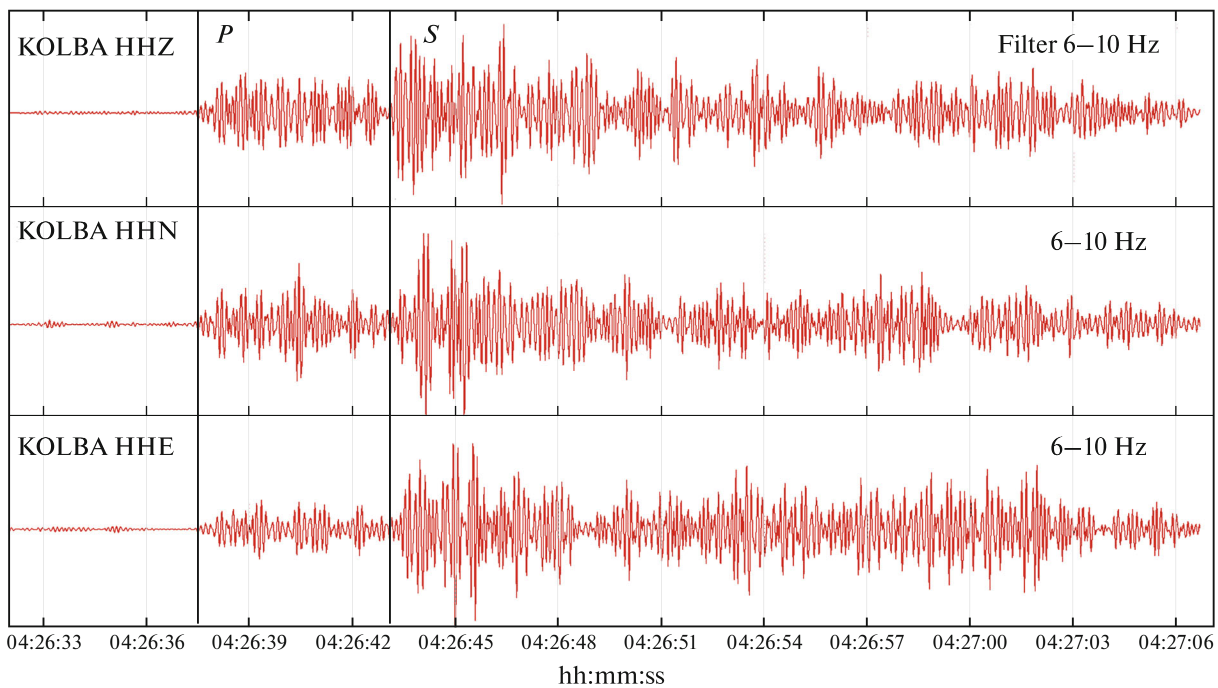

Fig. 7. Local seismic event recorded near port of Bukhta Sever on July 19, 2021.

Other local events are supposedly of a tectonic nature (Fig. 8), because their epicenters do not fit the locations of industrial enterprises in the region. Most earthquakes are clustered on the right shore of the Yenisei Gulf and are associated with several fault zones (Fig. 8). Given the small location accuracy, earthquakes may be associated with mapped fault zones (Fig. 8). Moreover, earthquakes in the Kara Sea have begun to be recorded, although this region was previously believed to be aseismic (Fig. 8).

Teleseismic Earthquakes

Despite the fact that the priority task when processing data from the Kolba seismic station is distin-

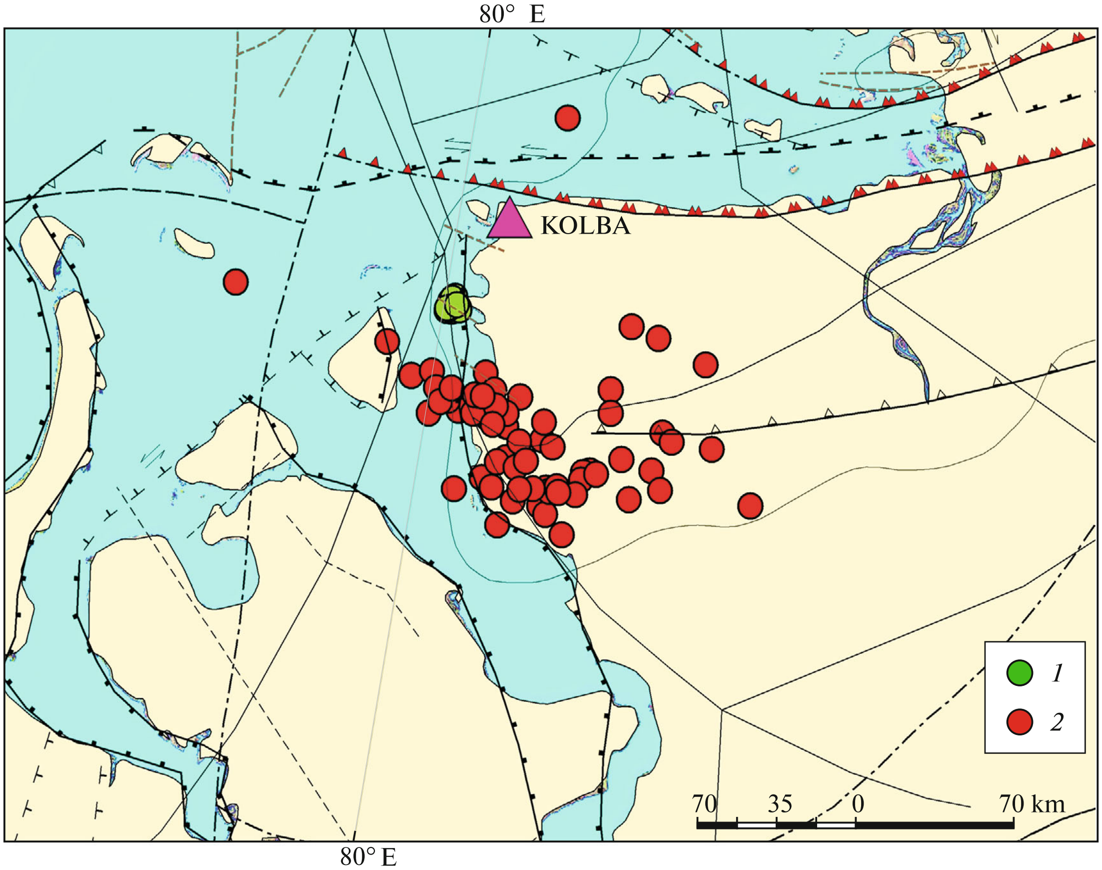

Fig. 8. Spatial distribution of local events in Kolba seismic station area: (*1*) technogenic events near port of Bukhta Sever; (*2*) earthquakes.

guishing regional and local earthquakes, we also assessed how far (teleseismic) earthquakes are recorded. Although analysis was performed only for the first month of the station's operation, it appeared to be sufficient: more than 200 teleseismic earthquakes had been recorded for the period from October 11 to November 22, 2020. According to the obtained recurrence plot for teleseismic earthquakes, $m_{b\text{rep}} = 5.3$, which corresponds to the respective values for the stations performing teleseismic monitoring.

Events of Glacial Nature

Except for earthquakes and technogenic events, the station records pulsing microtremors supposedly related to glacial activity. Similar pulses are recorded by other Arctic stations of the Arkhangelsk Seismic Network (Antonovskaya et al., 2018). Icequakes are characterized by short (up to 3 s) pulses. They are identified using a 1.5–3 Hz filter (Fig. 9), although they can also be seen in the initial signal.

The number of daily recorded icequakes can be up to several hundreds. Since the station is located near the coastline, it can be suggested that such a large number of icequakes is related to nearshore hummocking (piling up of broken sea ice during its deformation from lateral compression). A study of icequakes in the records from the Kolba seismic station, comparison with icequakes recorded by other stations, and obtaining of temporal and temperature dependences require particular research beyond the scope of the present article.

CONCLUSIONS

The operational results of the Kolba seismic station give grounds to confirm its high recording capabilities for seismic events in the western sector of the Russian Arctic and adjacent areas. The maximum recording capability is observed in winter, when the microseismic noise level decreases by two orders of magnitude. The station records both regional earthquakes occurring in seismically active zones of the Arctic and technogenic events from the Norilsk area, related to industrial activity). Local earthquakes are clustered in the Yenisei Gulf, and some of them are technogenic (related to activity at Bukhta Sever). Seismic events have been recorded within the Kara Sea shelf zone,

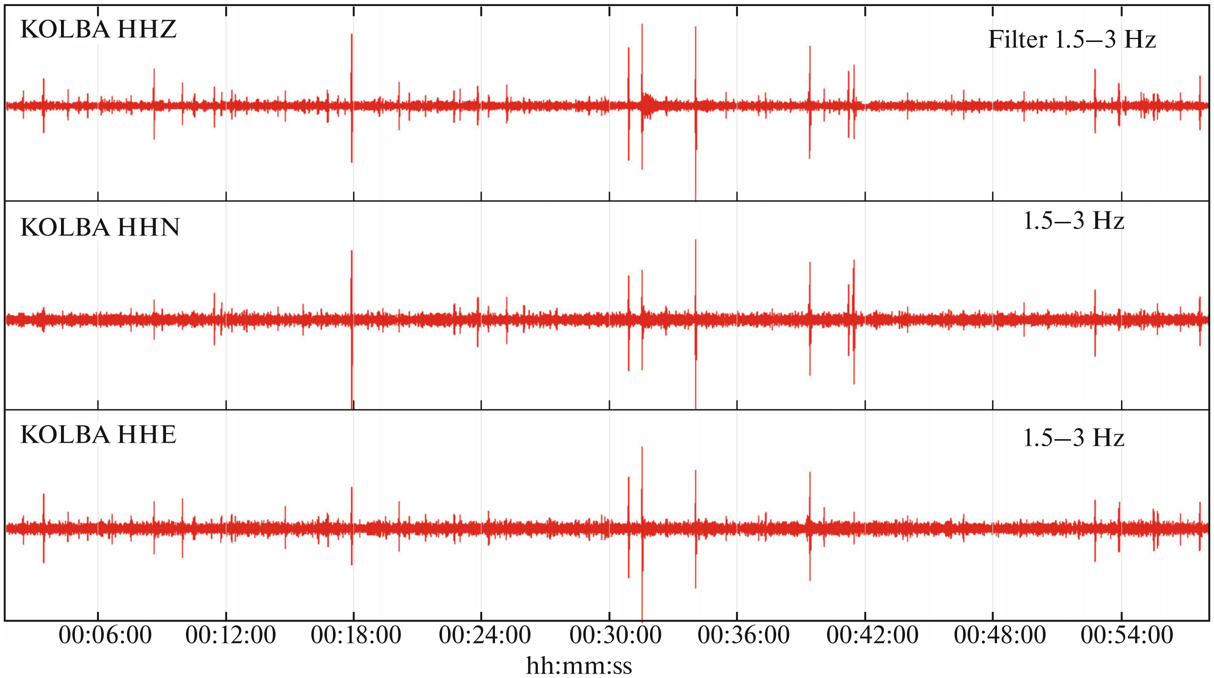

Fig. 9. Icequake waveforms.

although the entire sea was earlier believed to be aseismic. Analysis of the microseismic noise level in the vicinity of the Kolba station has made it possible to determine the frequency intervals of reliable recording for events of different nature.

Thus, the Kolba seismic station provides additional information about modern seismicity in offshore and platform areas around the Northern Sea Route, and this information should be taken into account when designing and monitoring critical facilities.

ACKNOWLEDGMENTS

The authors thank A.I. Koshkin, lead programmer at the Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences, for assistance in putting the Kolba seismic station into operation.

FUNDING

The study was carried out within the state task for the N. Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences, state registration no. 122011300389-8.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

Akimov, A.P. and Krasilov, S.A., Software complex WSG System of processing seismic data, RF Certificate of State Registration of Software no. 2020664678, 2020.

Antonovskaya, G.N., Konechnaya, Ya.V., Vaganova, N.V., Basakina, I.M., Morozov, A.N., Shakhova, E.V., Mikhailova, Ya.A., and Danilov, K.B., Contribution of the unique scientific facilities Arkhangelsk Seismic Network to the Russian Arctic seismicity study, *Geodin. Tektonofizika*, 2022, vol. 13, no. 2, p. 0587. https://doi.org/10.5800/GT-2022-13-2-0587

Antonovskaya, G.N., Kovalev, S.M., Konechnaya, Ya.V., Smirnov, V.N., and Danilov, A.V., New information about the seismicity of the Russian Arctic based on the work of the seismic station Severnaya Zemlya, *Probl. Arktiki Antarktiki*, 2018, vol. 64, no. 2, pp. 170–181. https://doi.org/10.30758/0555-2648-2018-64-2-170-181

Antonovskaya, G., Morozov, A., Vaganova, N., and Konechnaya, Ya., Seismic monitoring of the European Arctic and adjoining regions, *The Arctic: Current Issues and Challenges*, Pokrovsky, O.S., Kirpotin, S.N., and Malov, A.I., Eds., New York: Nova Science Publishers, 2020, pp. 303–368.

Antonovskaya, G.N., Basakina, I.M., Vaganova, N.V., Kapustian, N.K., Konechnaya, Ya.V., and Morozov, A.N., Spatiotemporal relationship between Arctic mid-ocean ridge system and intraplate seismicity of the European Arctic, *Seismol. Res. Lett.*, 2021, vol. 92, no. 5, pp. 2876–2890. https://doi.org/10.1785/0220210024

Atlas Geologiya i poleznye iskopaemye shel'fov Rossii (Atlas on Geology and Fossile Resources of the Russian Shelfs), Alekseev, M.N., Ed., Moscow: Nauchnyi Mir, 2004.

GEOFON, 2022. http://geofon.gfz-potsdam.de/fdsnws/dataselect/1/builder.

Dyagilev, R.A., Package of applied software for special problems of seismic monitoring: Spectral analysis of seismic noise. Perm: Gornyi Inst., Ural. Otd. Ross. Akad. Nauk, 2012. http://mail.mi-perm.ru/solution/nr?show_id=29. Cited August 4, 2022.

IRIS, 2022 http://service.iris.edu/fdsnws/dataselect/docs/1/builder/.

International Seismological Centre. On-Line Bulletin. https://doi.org/10.31905/D808B830

Federal Research Center Geophysical Survey, Russian Academy of Sciences, 2022. http://www.gsras.ru/new/ssd.htm.

Software compelx EL (ELRESS), 2022. http://www.krsc.ru/EL.

Kremenetskaya, E., Asming, V., and Ringdal, F., Seismic location calibration of the European Arctic, *Pure Appl. Geophys.*, 2001, vol. 158, nos. 1–2, pp. 117–128. https://doi.org/10.1007/PL00001151

Morozov, A.N., Vaganova, N.V., Asming, V.E., and Evtyugina, Z.A., ML scale for wester part of the Eurasian Arctic, *Ross. Seismol. Zh.*, 2020a, vol. 2, no. 4, pp. 63–68. https://doi.org/10.35540/2686-7907.2020.4.06

Morozov, A.N., Vaganova, N.V., Konechnaya, Y.V., Zueva, I.A., Asming, V.E., Noskova, N.N., Sharov, N.V., Assinovskaya, B.A., Panas, N.N., and Evtyugina, Z.A., Recent seismicity in northern European Russia, *J. Seismol.*, 2020b, vol. 24, no. 1, pp. 37–53. https://doi.org/10.1007/s10950-019-09883-6

Morozov, A.N., Antonovskaya, G.N., Asming, V.E., Baranov, S.V., Boldyreva, N.V., Vaganova, N.V., Vinogradov, Yu.A., Konechnaya, Ya.V., Starkova, N.N., Fedorov, A.F., Fedorov, I.S., and Shibaev, S.V., Arktika, *Zemletryaseniya Rossii v 2019 godu* (Earthquakes of Russia in 2019), Obninsk, Kaluga oblast: Fed. Issled. Tsentr Edinaya Geofiz. Sluzhba Ross. Akad. Nauk, 2021a, pp. 33–36.

Morozov, A.N., Vaganova, N.V., Antonovskaya, G.N., Asming, V.E., Gabsatarova, I.P., Dyagilev, R.A., Shakhova, E.V., and Evtyugina, Z.A., Low-magnitude earthquakes at the eastern ultraslow-spreading Gakkel Ridge, Arctic Ocean, *Seismol. Res. Lett.*, 2021b, vol. 92, no. 4, pp. 2221–2233. https://doi.org/10.1785/0220200308

NORSAR. Regional reviewed, 2022. https://www.norsar.no/extranet/bulletins/.

Peterson, J., Observation and modeling of seismic background noise, US Geological Survey Open-File Report, pp. 93–322.

Pubellier, M., Rossi, P., Petrov, O., Shokalsky, S., St-Onge, M., Khanchuk, A., and Pospelov, I., CCGM, CGMW. Tectonic map of the Arctic (TeMAr), 2018. https://doi.org/10.14683/2018TEMAR10M

Spencer, A.M., Embry, A.F., Gautier, D.L., Stupakova, A.V., and Sorensen, K., *Arctic petroleum geology, Geological Society Memoir no. 35*, London: Geological Society, 2011. https://doi.org/10.1144/M35.0

Unique Research Facility Arkhangelsk Seismic Network, Laverov Federal Center for Integrated Arctic Research, Ural Branch, Russian Academy of Sciences, 2022. http://fciarctic.ru/index.php?page=geoss.

US Geological Survey, Search Earthquake Catalog. https://earthquake.usgs.gov/earthquakes/search/. Cited August 4, 2022.

Translated by N. Astafiev