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About seismic observations on Sakhalin with the use of molecular-electronic seismic sensors of new type

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Abstract. To conduct complex geophysical observations in the area of the Central Sakhalin Fault, an experimental geophysical test site was created, including a broadband molecular electronic type station and a new development of the Molecular Electronics Center - molecular electronic hydrophone. A module for placing a molecular-electronic seismometer at the test site has been developed and arranged. The noise level of the seismometer was analyzed and compared with the reference data. The results of hydroacoustic observations of weak earthquakes in the area of the Central-Sakhalin fault using a molecular-electron hydrophone are presented. The characteristics of the recorded acoustic emission signals from earthquakes perceived by the hydrophone station (frequency spectrum, arrival times of seismic waves) are investigated. The issues of operation and maintenance of molecular-electronic sensors with seismic signal data logger at various stages of seismological observations (setting up equipment, acquisition and storing data) were considered. The analysis of recording capabilities of seismic equipment was performed. Conclusions about the advantages and disadvantages of molecular-electronic sensors and their use on Sakhalin are made.

1. Introduction

The history of the direction associated with the creation of motion sensors, using an electrochemical (molecular-electronic) cell as a sensitive element, has a number of decades. During this time, a theoretical base of transfer processes was created in a transforming element, technologies for creating such cells, methods of connecting to electronics were developed, and samples of sensors of various types were made [1]. The developed seismometers are characterized by the absence of elements of precise mechanics and moving mechanical parts, which guarantees their high reliability, ease of operation, resistance to undesirable external influences, as well as relatively low cost. Until recently, the experience of operating seismometers of this type on Sakhalin Island was limited to temporary seismic observations of Institute of Marine Geology and Geophysics (IMGG) in the Kholmsk district in August 2006 [2] and testing seismometers at the Sakhalin branch of the Geophysical Survey of the Russian Academy of Sciences (SB GS RAS) in 2004. In both cases, the CME4011 short-period seismometers of the Russian company R-Sensors were used. Currently, R-Sensor offers broadband and short-period seismometers, seismic accelerometers, geophones and other seismic and geophysical instruments based on the physical principles of molecular-electronic signal conversion and the use of liquid inertial mass. A new stage in gaining experience in using molecular electronic devices on Sakhalin was the work on Russian

Foundation for Basic Research (RFBR) project cflled “Study of trigger deformation effects based on the data on Sakhalin’s seismicity using a new type of seismic sensors”. This project is carried out by IMGG together with the specialists of the SB GS RAS and the Moscow Institute of Physics and Technology. To ensure continuous observations within the framework of the project, a site of complex geophysical observations was deployed in the South of Sakhalin. The choice of the location of the site is determined primarily by the fact that most of the population of the Sakhalin region lives in the south of the island and therefore the issues of seismic monitoring come out on top. At the same time, most of the earthquakes occurring are located in the central part of the south of the island, in the area of the Central-Sakhalin Fault. Taking into account these facts, as well as data on the medium-term seismic hazard forecast in the territory of southern Sakhalin [3], in 2018, a the experimental test site for seismic monitoring was created in the village of Petropavlovskoye, Aniva District, Sakhalin Region (figure 1).

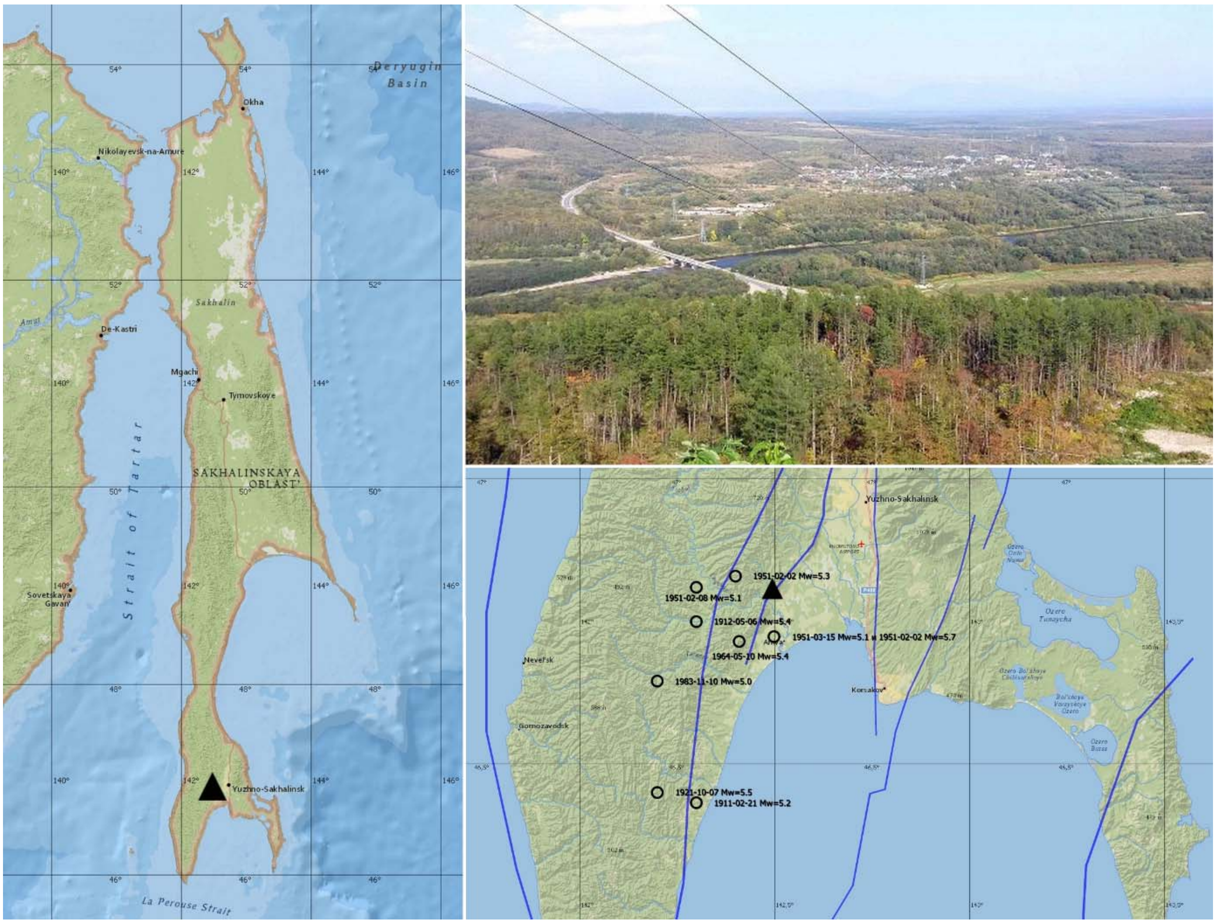

Figure 1. The location of the test site on the map of Sakhalin. Inset on the right is a map of South Sakhalin with major faults [4] and epicenters of large earthquakes (M≥5.0) [5].

2. Observation equipment

The main equipment of the experimental test site for seismic monitoring is the molecular-electronic broadband seismometer CME-6111 from the R-Sensor company. The CME-6111 seismometer combine the low-noise molecular-electronic sensing element (transducer) and the electrodynamic feedback which results in a very flat response over a wide frequency range, high dynamic range and greatly improved time and temperature stability of the instrument parameters. Like other molecular-electronic instruments, the CME- 6111 seismometer is very rugged and does not require any special means or procedures for transportation and installation. The only procedure to start its operation is to place the seismometer on a rigid horizontal surface, turn it on and wait for several minutes. The seismometer can be used in various areas including permanent stations and field surveys. The sensing element of a MET transducer consists of two hermetically sealed housings filled with electrolyte connected by a channel with electrodes across it. The electrodes are separated by perforated dielectric spacers. The electrolyte plays the role of the inertial mass, while hydrodynamic impedance of the sensing element acts as the damping mechanism providing a feedback for stabilization of the transfer function [6]. The seismometer has a wide dynamic range with a bandwidth of 0.0167 (60 s) - 50 Hz and a sensitivity of 2000 V / (m / s). To install the seismometer has been designed and equipped a special pressurized module, shown in figure 2.

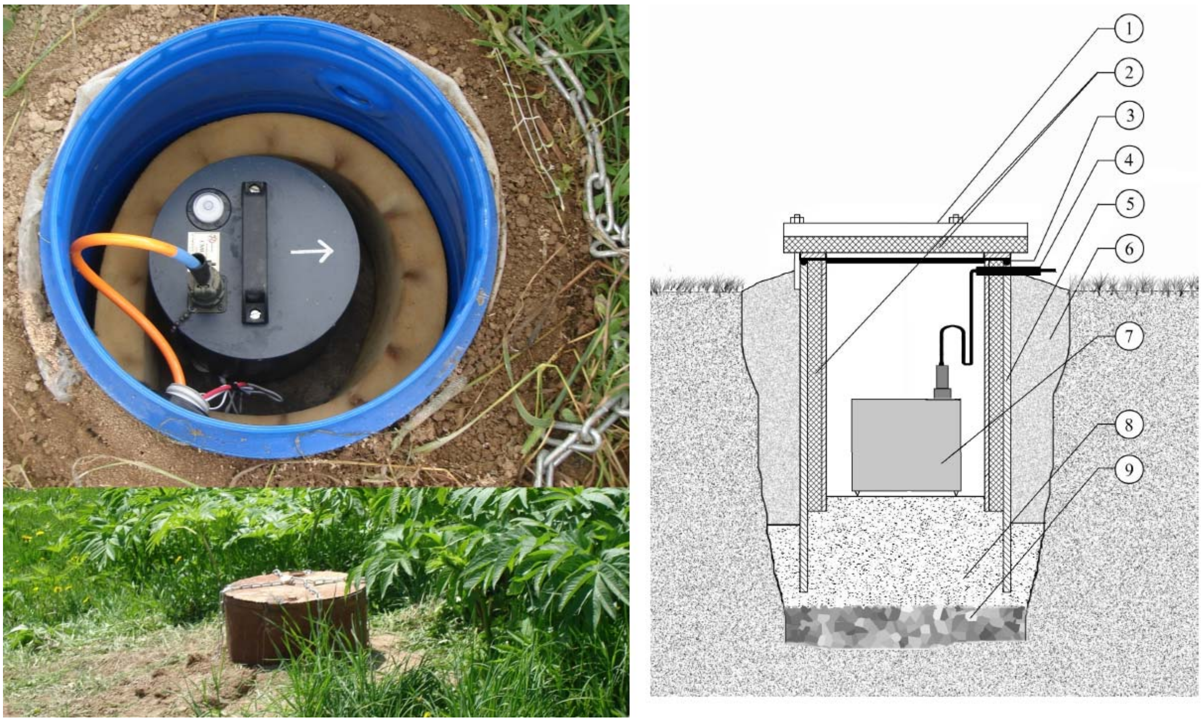

Figure 2. Equipment installation seismometer module (1. Module cover; 2. Heat insulation; 3. Sealing ring; 4. Input signal cable; 5. Module housing; 6. Filling; 7. CME-6111 seismometer; 8. Concrete base; 9. Crushed stone).

To register the hydroacoustic signals at the test site, an experimental molecular electronic hydrophone was installed [7]. A hydrophone is a device for measuring pressure changes in an acoustic wave in liquid and gaseous media. The hydrophone is made using an electrochemical converter that transforms the movement of the working fluid into a detected current, providing sensitivity to pressure variations in the frequency band of 0.02–200 Hz with a high conversion factor of at least 1.5 mV / Pa. The hydrophone case is sealed and has compact dimensions (diameter 33 mm, height 47 mm). The installation of the hydrophone was made in a specially prepared flooded borehole with a depth of 2 meters.

Data logger NDAS-8226 is used as a seismic signal recorder. NDAS-8226 is a seismic data acquisition system mostly designed for autonomous data recording in field environments. NDAS-8226 is based on a 6-channel 24-bit resolution ADC ensuring low noise and low power consumption. The instrument uses a USB and Wi-Fi connection for data transfer and system configuring and a 32 Gb internal storage memory for offline recording. NDAS-8226 includes a precision regulated VCO quartz crystal with the real-time GPS/GLONASS clock adjustment. This provides synchronization accuracy better than an error of timing of 1 μsec. The case is rugged and waterproof.

To provide remote access and control of the operation of the recording equipment, 4G modem-router is used, which allows you to control the operation of the system through the Internet. The modem-router connects to the NDAS-8226 using a Wi-Fi connection, which allows it to be located regardless of the location of the NDAS-8226. The power supply of the system is provided by a 12-volt power source with an external battery, which guarantees the operation of the complex in the event of a power outage. The scheme of the complex of observations is shown in figure 3.

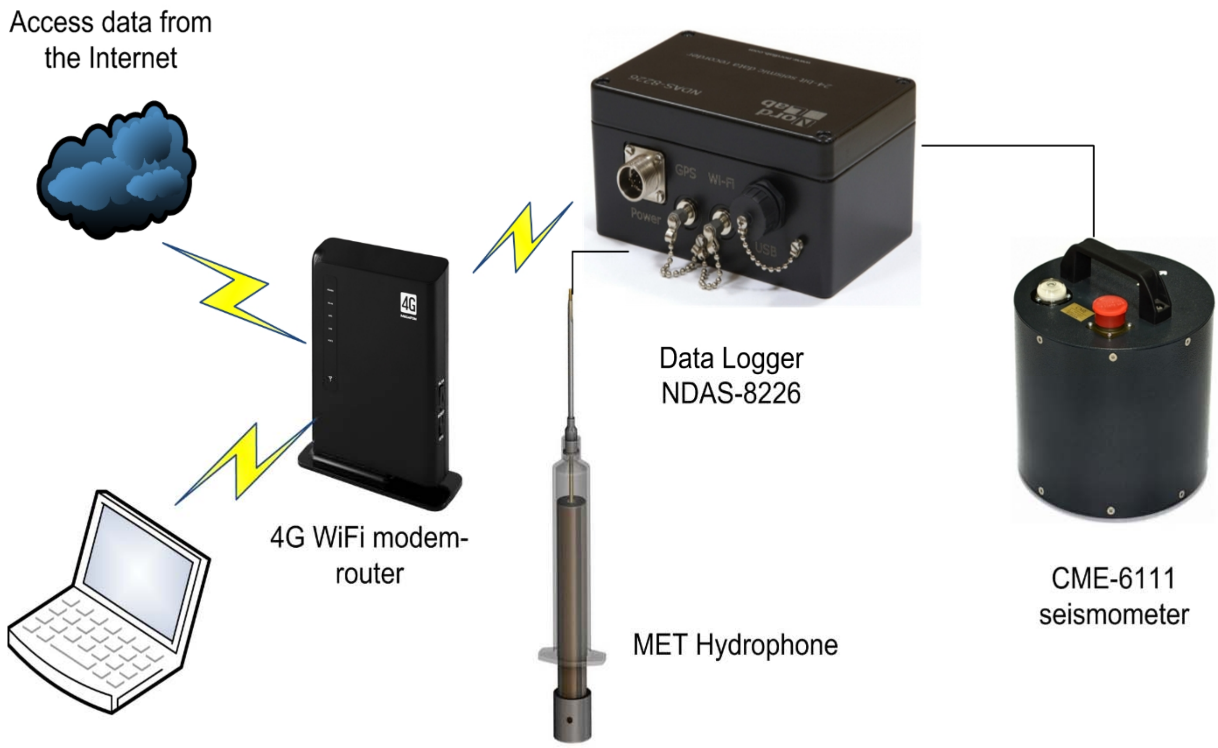

Figure 3. Equipment for seismic monitoring complex.

To set up and control the operation of the complex, the NDAS software is used. The NDAS software allows doing: initial configuring of the device prior to operation, selection of operation mode, parameters setting, system status monitoring, registration of seismic signals on the built-in SD card, real-time signal preview, sending test signals on the connected sensors.

3. Results of the observations

The spectral density of seismic noise of the CME-6111 seismometer was estimated. For the calculation, the software complex DIMAS (Display, Interactive Manipulation and Analysis of Seismograms) was used [8]. The noise level was estimated against Peterson models (low and high noise models), which are the benchmarks for estimating the level of seismic noise in the vicinity of the seismic station operation [9]. As can be seen from figure 4, in the frequency range in which the vast majority of regional events (1–10 Hz) are recorded, all the curves are almost identical and in the daytime only slightly exceed the upper limit of the Peterson model, which is explained by the presence of man-made noise in seismic noise at frequencies above 2 Hz above. In general, the noise level at the registration point is quite low and in combination with the use of standard filters used to identify events does not make it difficult to determine the input signals of various types of waves.

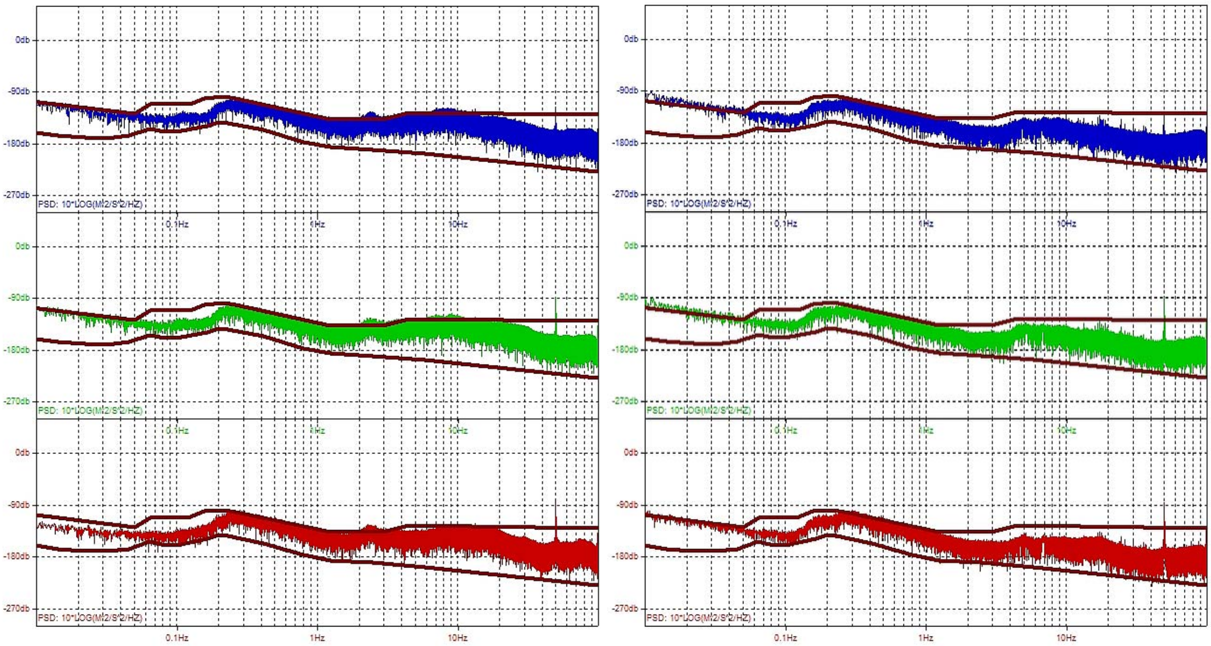

Figure 4. The spectral density of seismic noise of the CME-6111 seismometer (on the left - daytime, on the right – nighttime).

Processing of local seismic events, registered with the equipment of the test site, was also carried out in the DIMAS software complex. A local earthquake is characterized by the presence of two main waves Pg and Sg. In the case of weak earthquakes, it is very important to distinguish these waves from interference. P waves usually have a clear introduction with a gradual smooth decrease in intensity, the group of S-waves is lower frequency and it is not a problem to isolate them. As an example of recording a local event, the earthquake 2019-01-03 (O = 08-54-15UTC; LAT 47.23N; LON 142. 46W; H = 12 km; ML = 3.1) is given (according to the operational catalog of the SF GS RAS) which occurred at a distance of about 50 km from the test site (figure 5).

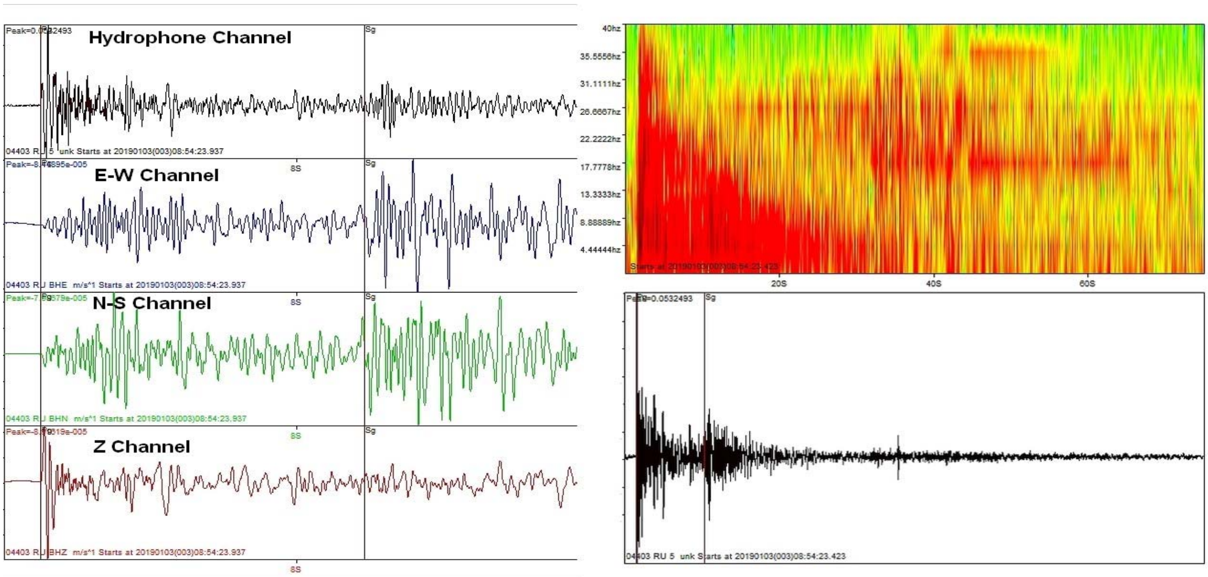

Figure 5. Recording a local seismic event with molecular electronic sensors. To the right is the spectrogram of this event, recorded by a hydrophone.

This is a local shallow earthquake, its record is characterized by a total short duration and high-frequency composition. Here we can see the records of the first arrivals of the waves Pg and Sg. Both entries have a clear and intense start. On the hydrophone recording, we also see a clear P-wave entry. Additionally, we studied the dependence of the amplitude of the signal at different frequencies over time, by constructing a spectrogram. The signal was passed through a set of bandpass filters. Then, the amplitude envelope of the signal in each band was calculated. As a result, the level of signal amplitude change over time at different frequencies was obtained, and the spectrogram was plotted. Figure 5 (right) shows the waveform and spectrogram of this event from the recordings of the hydrophone. Here, the moments of the arrival of the direct P and S waves as responses of the Pr and Sr aquatic environment are confidently detected. Registered hydroacoustic responses to P and S waves occupy a frequency range up to approximately 40 Hz.

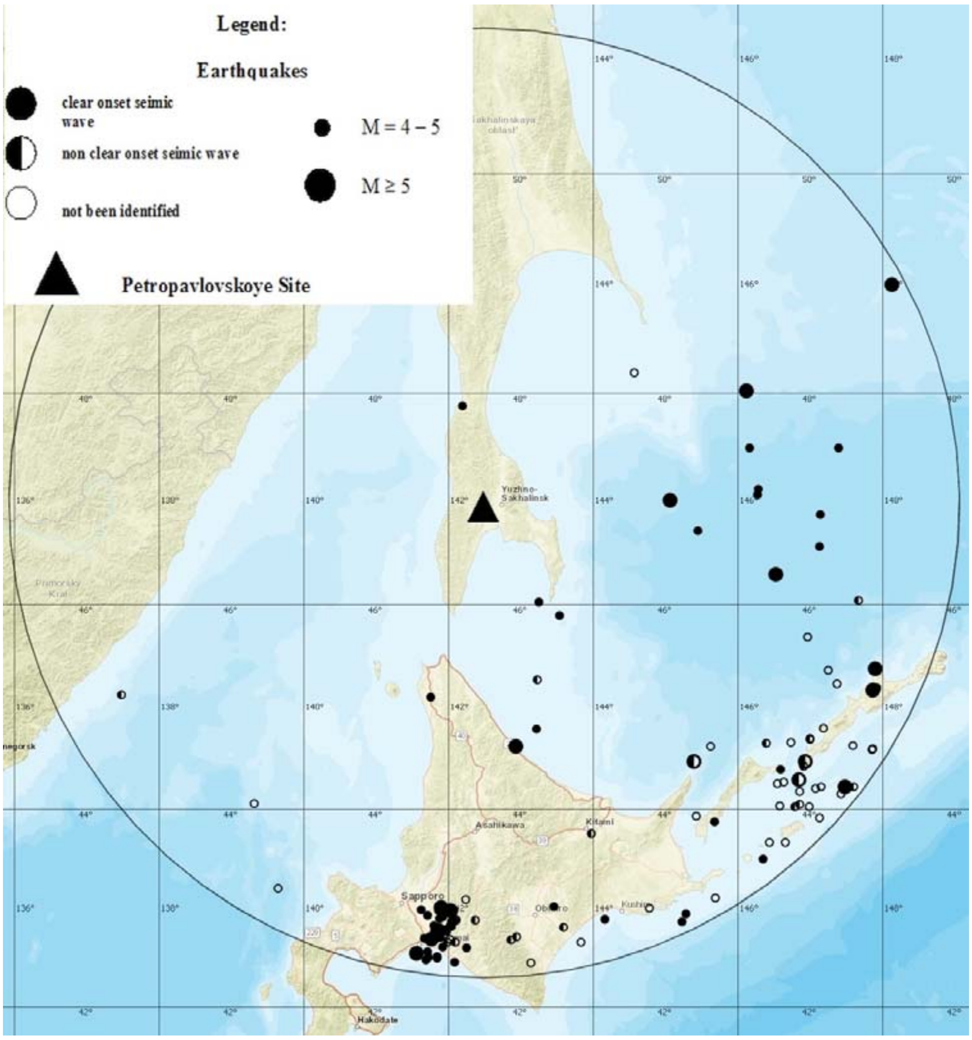

Figure 6. The map of earthquake epicenters, based on the analysis of the operational catalog of the SB GS RAS with M≥4 (June-September 2018) by the seismological complex CME-6111+ NDAS-8226.

To evaluate the performance of the complex for registration of regional events, the operational catalog of the SB GS RAS of four months (June-September 2018) with M≥4 was used. The catalog includes 110 earthquakes within a radius of 500 km from the test site. Analysis of the records showed that out of 110 earthquakes within a radius of 500 km from the landfill there is a clear onset seismic wave for 56 events, 21 events can be defined as a non clear onset seismic wave, and 33 earthquakes were not identified (figure 6). Thus, 70% of seismic events with M≥4 within a radius of 500 km from the landfill are reliably recorded, which allows to conclude that the CME-6111 + NDAS-8226 equipment set is quite good. It was found that the Guralp CMG-6TD traditional electro-mechanical seismometer has similar results in recording these seismic events. The comparison was carried out on the basis of the analysis of the records of these seismic events with a Guralp CMG-6TD seismometer installed at the seismic station of the SF GS RAS “Novoaleksandrovsk” (NVA) under the Tsunami warning program [10]. This seismometer has similar technical characteristics. The location of the NVA station (33 km from the test site) and similar geological conditions suggest that the conditions for comparison are correct..

4. Conclusions

For seismic monitoring of Sakhalin, electromechanical type seismic receivers are mainly used. However, the use of molecular electronic sensors has considerable promise. As the tests at the test site showed, instruments of this type in terms of the main metrological indicators (frequency and dynamic ranges, level of intrinsic noise) approach the best samples of electromechanical seismic receivers. At the same time, they are stable in shocks, changes in humidity and temperature, they work at different angles of inclination to the vertical, they are economical in power supply. Comparative analysis of records not only local and regional, but also remote (teleseismic) seismic events showed that the records of strong earthquakes also do not differ from the records by traditional stations and molecular-electronic devices can be used in processing current seismological information.

The results of hydroacoustic signals records show that the use of compact molecular-electronic hydrophone systems can record regional earthquakes, including weak magnitudes, record local microearthquakes, estimate earthquake parameters, detect geoacoustic emission signals, and identify stress-deformed states of geological structure.

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