Change in the Level of Microseismic Noise During the COVID-19 Pandemic in the Russian Far East

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Abstract—With the outbreak of the COVID-19 pandemic, many seismologists all over the world have noted a sharp (up to 30–50%) decrease in the daily background seismic noise during the period from March to May, 2020 (Lecocq et al., Science 369(6509):1338–1343, 2020). The authors studied the influence of the self-isolation regime introduced in the Russian Federation from March 30, 2020 and, as a consequence, the restriction of the work of public institutions and the mobility of the population, on the quality of seismological observations at seismic stations in large cities of the Russian Far East for the period from March 23, 2020 to April 12, 2020. The work analyses the records of seismic noise by the seismic stations of Khabarovsk and Vladivostok located in busy parts of the cities and, accordingly, strongly influenced by anthropogenic impact, as well as it analyses the records of the Yuzhno-Sakhalinsk seismic station located in the relatively «calm» part of the city. Power spectra and temporal variations of microseismic noise levels for the listed above seismic stations were constructed based on the data of broadband seismometers records in the range of 1–20 Hz. The analysis of noise level variations with the data on the population mobility was carried out on the basis of self-isolation index by Yandex, which shows the level of town activity over a selected period. The main sources of the increased microseismic noise at seismic stations were identified.

Keywords: Coronavirus infection, Anthropogenic seismic noise, Spectral density, “Cultural” noise.

1. Introduction

Background microseismic field is an object of studies and experiments for many years. The most studied problems are those, in which the parameters of microseismic radiation are related to the parameters of primary sources of elastic energy radiation (Kapust’yan, 2001). Atmospheric and oceanic phenomena are the sources of microseisms within the frequency range less than 1 Hz. At higher frequencies (from 1 to 20 Hz) seismic noise includes «cultural» or, in other words, anthropogenic and technogenic noise (industrial production, transport and other human activities) (Bormann & Wielandt, 2013). Considering, that most stations have an average level of noise power in comparison with average world Peterson noise curves and at the frequencies above 1 Hz in the daytime, the noise level increases by at least an order of magnitude due to anthropogenic activity (Malovichko et al., 2020). Growth of modern cities, rapid development of their transport and industrial infrastructure inevitably bring to greater anthropogenic impact on the environment. In this regard, it becomes urgent to monitor spatial distribution of surface seismoacoustic vibrations in various frequency ranges. The measures to mitigate the effects of the pandemic of coronavirus disease 2019 (COVID-19) have caused far-reaching changes in human activities, resulting in a decrease in seismic noise over several months by up to 50% (Lecocq et al., 2020). The 2020 seismic noise quiet period is the longest and most noticeable global reduction in anthropogenic seismic noise on record.

The COVID-19 pandemic began at the end of 2019, it results in the fact that the entire population of the world has sharply reduced its social activity. This also affected the Russian Federation (RF). On March 28, the Decree «On the declaring of non-working days in the Russian Federation» was issued, which establishes non-working days from March 30 to April 3, 2020 (On the declaring …, 2020), which was extended from April 4 through April 30, 2020.
inclusive (On the measures for ensuring ..., 2020). These measures resulted in suspension or limitation of the activities of individual enterprises, regardless of their organizational and legal form throughout the country, shopping centers, cinemas, schools, scientific and educational organizations were closed, and a special procedure for the movement of transport was established. The works (Lecocq et al., 2020; Xiao et al., 2020; Yabe et al., 2020) show that the degree of traffic noise reduction in cities depends directly on the district characteristics, and the current situation and the corresponding social reaction associated with the spread of COVID-19 directly affects the value of seismic noise reduction. The measures taken in the Russian Federation have significantly reduced the level of anthropogenic seismic noise generated, for instance, by road and rail transport or building activity. Such a noise often interferes with the activity, which is sensitive to extraneous vibrations, including earthquake monitoring. The reduction in seismic noise as a result of COVID-19 recorded by seismic stations has allowed scientists from different countries estimating the level of “cultural” noise in the urban environment (Ajeet et al., 2020).

This work studies the change in the level of seismic noise caused by the non-working day regime introduced in the territory of the Russian Federation in terms of the COVID-19 pandemic, by the example of three cities of the Russian Far East (RFE)—Vladivostok, Khabarovsk and Yuzhno-Sakhalinsk for the period from March 23 until April 12, 2020.

2. Seismic Data and Methods

The Far East is one of the largest areas of the Russian Federation situated in the eastern part of the country. This region plays an important role in the social, cultural and economic development of the country. For the study, we have selected three largest cities in the south of the Far East of the Russian Federation with a population about 600 thousand people in Vladivostok (the regional center of the Primorsky Krai), about 650 thousand people in Khabarovsk (the regional center of the Khabarovsk Krai) and about 200 thousand people in Yuzhno-Sakhalinsk (the regional center of the Sakhalin region). Seismic stations of the network of the Sakhalin Branch, Geophysical Survey, Russian Academy of Sciences (GS RAS) were used to carry out the work. Figure 1 demonstrates a map of the southern part of the Far East of RF highlighting the studied cities and seismic stations installed there.

For these settlements the impact of the COVID-19 pandemic on public life can be assessed by means of Yandex self-isolation index (Zemtsov & Baburin, 2020) in the period before the self-isolation and during two weeks after it. «Self-isolation index is an integrated indicator, which is computed according to the data on using the various Yandex’s applications and services. It can be used for information purposes to roughly estimate the situation. Self-isolation is one of the fundamental measures in the fight against the COVID-19 pandemic. In order to have an idea of how Russians people meet this challenge, the score, which indicates the self-isolation level in different localities, is computed. To this end, the level of urban activity is compared at the current moment and on a typical day before the epidemic. If it is the same as during the rush hour of a normal weekday, then the level of self-isolation is low, it is 0 points. If the city is as quiet as at night, this is 5 points. The higher the score, the more difficult it is for the virus to spread» (https://yandex.com/company/researches/back-to-life). Figure 2 shows the Yandex self-isolation index by the cities, accompanied with the notes about the restrictions that come into effect.

Seismic stations (s./st.) in each of the cities are in different conditions in terms of registration settings. In Vladivostok and Khabarovsk s./st. are located in the central districts with the greatest human activities in contrast to Yuzhno-Sakhalinsk, where s./st. is installed in rather «quiet» place (forest). This can be seen in Fig. 3, which shows the photos of the location of seismic stations.

The research material was the three-component seismic records from broadband and short-period seismometers, obtained from the stations, which are located in the mentioned above cities. For illustrative purposes, full characteristics are presented in Table 1.

All the stations are registered in International Seismological Centre (ISC) (International Seismological Centre, 2021) are the part of the large-scale research facilities «Seismic infrasound array for
monitoring Arctic cryolitozone and continuous seismic monitoring of the Russian Federation, neighbouring territories and the world» of the Sakhalin Branch, Geophysical Survey, Russian Academy of Sciences (https://ckp-rf.ru/usu/507436/, http://www.gsras.ru/unu/). Stations are equipped with the broadband seismometers produced by Streckeisen (https://streckeisen.swiss/en/productst/sts-2/) («Khaba-
rovsk» and «Yuzhno-Sakhalinsk» stations) and the broadband seismometer developed during the Soviet period (Aranovich et al., 1974) for «Vladivostok», as well as with the various short-period seismometers (https://www.guralp.com/documents/DAS-040-0001.pdf; https://www.passcal.nmt.edu/webfm_send/440; http://geotechru.com/three-component-seismometer-spv-3k/). The devices by Kinematics (https://kinematics.com/wp-content/uploads/2017/04/data_sheet-q330hr-broadband-seismic-system-quanterra.pdf) and Hakusan (https://www.hakusan.co.jp/products/doc/CAT_LS-7000XT_151005.pdf) companies were used as recorders of seismic signals.

The methodology for studying the spectral-temporal characteristics of seismic noise included, first of all, the selection of seismic records required for the analysis, computation of the spectral density of seismic noise (McNamara & Buland, 2004), as well as the microseisms analysis by means of graphs. When computing, the DIMAS software suite (Droznina, 2011) was used, by means of which the seismic noise records during the period from March 23 to April 12, 2020, were initially reduced to the unique signal sampling frequency (20 Hz) using the decimation algorithm. Then the signal envelope was calculated using the formula $y[i] = y[i - 1] + \frac{(\text{abs}(x[i]) - y[i - 1])}{N}$, where: $x[i]$—initial signal points; $N = 1800$ s (length of a window in seconds). Thus, we obtained the values of amplitude of the seismic noise signal averaged within the 30-min intervals which were used for the graphs plotting. As well the analysis of the power spectral density (PSD) was carried out. To plot the graphs of the noise spectral density on seismograms, the nine-hour segments of the records from the seismometers vertical channels (during the day local time) were selected for a «noisy» day of a working week before the restrictions introduced (March 24) and a «quiet» day of self-isolation period (April 11).
To analyze the spectral structure of seismic noise, the Spectrum program was applied, which is a part of the methods developed and patented by the Geophysical Survey, Russian Academy of Sciences (RU 2461847 …, 2012) and aimed at studying the long-term seismic low-amplitude signals, the source of which are various large industrial installations, buildings and structures oscillating at natural frequencies, industrial noises of cities, as well as the seismic fields in the Earth’s interior.

3. Results and Conclusion

To determine the average noise level, one-week period was taken before the self-isolation beginning and two weeks after it (from March 23 to April 12, 2020) and noise envelopes were constructed for each station with the overlay Yandex self-isolation index (Fig. 4). And although the average noise level and its temporal changes vary between stations in each city, the general trend of the usual level of social activity and its decrease during the population self-isolation period is similar. There are some differences in the ratio of the noise level recording in Yuzhno-Sakhalinsk between the broadband and short-period seismometers. As mentioned above, the broadband STS-2 is installed in a seismic pavilion located in a forest, and the short-period SPV-3 K is installed in the basement of the Geophysical Survey building. In Fig. 4c, the noise level on the record from SPV-3 K clearly agrees with the periods of activity of the service personnel increasing on working days and decreasing on weekends, while the noise level at STS-2 has a smoother line and evident noise peaks are clearly expressed in three impulses only. Such impulse anomalies can be traced on the records from the stations of all the cities; they were on March 25, April 1, and April 5, 2020, though the social activity has to be low during these days according to the Yandex self-isolation index. It should be noted that when constructing the average seismic noise envelope, according to the formula described in the previous section, records of strong seismic events inevitably contribute to the result. This is explained by the fact that the level of peak velocity values according to instrument data, in the event that they register earthquakes, significantly exceeds the seismic noise level. Accordingly, with an averaging window length of 1800s, the peak values exert their influence on the constructed envelope precisely during this time, which is shown in Fig. 4.

According to the above, the first two anomalies are strong seismic events: on March 25, an
earthquake occurred in the area of Paramushir Island with \( Ms = 7.5 \) (http://www.gsras.ru/cgi-bin/new/quake_stat.pl?sta=20201185&l=1); on April 01, seismic stations recorded a seismic event in the USA (Western Idaho) with \( Ms = 6.5 \) (http://www.gsras.ru/cgi-bin/new/quake_stat.pl?sta=20201283&l=1), which is confirmed by the results of processing and bulletins of the stations. The April 5 anomaly is an atmospheric phenomenon (cyclone no. 28 according to (Mezentseva & Kaptyug, 2020)), affected the south of the Russian Far East during the day, the trajectory of which can be seen in Fig. 5a. In late March–early April, the studied area was significantly affected by cyclones and anticyclones (Fig. 5a). As for cyclones, at the beginning of the first decade of April, the Sea of Japan was influenced by a cyclone (no. 28), which developed south of Japan and, deepening significantly, moved to the northeast. The wind speed in the
sea was 8–13 m/s, heaving of the sea was 1–2 m. On April 4, near the southern coast of Primorye, under the high-altitude center, the cyclone deepened, and then slowly moved eastward. On April 6, it entered the Sea of Okhotsk, causing a wind of up to 13–18 m/s in the Sea of Japan, heaving of the sea of 3–4 m and heavy precipitation. The very next day, cyclone no. 33 had its impact. Figure 5c presents the graphs of the power spectral density of the noise at the «Yuzhno-Sakhalinsk» s./st. for a six-hour segment of seismic noise record made on the day of the cyclone passage (April 5, 2020) and, for comparison, segments of similar duration in «noisy» (March 24, 2020) and «quiet» (April 11, 2020) days.

Figure 5 shows, that atmospheric factors influence significantly exceeds the impact of technogenic seismic noise, that is especially evident for “quiet” stations similar to the «Yuzhno-Sakhalinsk» one.

The impact of technogenic seismic noise can be estimated by means of the power spectral density (PSD) analysis. Figure 6 presents a spectral power of six channels of three stations during the period before self-isolation, we’ll call it «noisy», and a «quiet» period during self-isolation. It is evident from the given figure, that «quiet» period has affected the recorded seismic noise in the wide frequency range. On the records of short-period stations, its effect disappears at frequencies below 1 Hz, where anthropic noise is weaker and become manifest in the frequency range of 1–20 Hz for «noisy» days, that indicates a cultural activity. The records of broadband seismometers (Fig. 6a) demonstrate a similar trend of change in power spectral density at the frequencies of 1–20 Hz, as for short-period ones, and there is an obvious decrease in microseismic noise during a «quiet» period at a frequency of up to 1 Hz.

The study results indicate, that the measures taken by the Government have caused the decrease in social and economic activity, that, in turn, has affected the seismic data from all the stations. However, this influence character changes depending not only on the locality, but also on the stations location, that does not contradict the data obtained by foreign authors (Pandey et al., 2020; Poli et al., 2020) and some studies fulfilled in the Russian Federation for Moscow (http://www.ceme.gsras.ru/new/news/news-20200402.htm).

Using the «Method of coherent separation of weak continuous seismic signals» (included in the SpectrumSeism program (Seleznev et al., 2021)), it was revealed that the effect of noise at different frequencies is uneven throughout the day. We assessed the impact at the frequencies of 4, 11 and 17 Hz (typical for manifestations of technogenic noise sources) for all the stations within the period from March 23 to April 03, 2020. This period included the
working week before the self-isolation regime was declared, weekends and the first non-working week after introducing the self-isolation regime. And although, as we have already found out, the average noise level and its change over time are different between the stations, there are several general characteristics. For illustration purposes (Fig. 7), graphs of the noise level in local time of each city were plotted according to the data of short-period seismometers. These graphs have a clearly pronounced diurnal variation of microseisms, that characterizes the population activity in the studied areas. Thus, morning and evening activities on «noisy» days are clearly expressed on the graphs of a signal amplitude fluctuations for the selected harmonics, while there is a flatter graph for the «quiet» days after self-isolation has been introduced.

We have also studied the spectral composition of the seismic noise and revealed its change depending on social activity. Figure 8 presents the averaged relative spectra of the signal recorded on the vertical components of the short-period seismometers of three stations at 12:00 local time from March 23 to April 3 in the range of 5–20 Hz. March 23–27 are the days before the self-isolation regime has been declared, March 28–29—the weekends before a non-working week, March 30–April 3—non-working days. The graph clearly shows, that the seismic noise level within the 5–20 Hz frequency range significantly exceeds the noise level after the self-isolation beginning for most stations.

First of all, the excess of the amplitude of the seismic noise level can be distinguished in Fig. 8 within the entire frequency range for the «Yuzhno-Sakhalinsk» s./st. This testifies to the fact that, due to the isolation of the station from the noise of the city, the activity of the station personnel, limited after the self-isolation regime has been introduced, is, in fact, the only source of technogenic noise. For the «Khabarovsk» s./st., which is located in the central part of the city, there are separate frequencies, where significant excess of amplitudes is observed during the working «noisy» periods. Thus, there is a constant interference at a frequency of 16.7 Hz on the working days, that is typical of the operation of asynchronous three-phase industrial AC motors with a speed of 1000 rpm used in electric drives of various
devices, mechanisms and machines (pumps, fans, compressors, etc.), which is obviously related to the operation of the building, where the seismic station is located.

As a result of reducing the noise level, the seismic events recording is considerably simplified. As an example, consider the record on seismograms of two earthquakes occurred in the Qinghai region (China), which have the same coordinates, depths and magnitudes. The first earthquake occurred on 06.05.2018 (09:23 UTC; 34.55 N, 96.47E; H = 15 km; Mb = 5.0), the second one took place on 01.04.2020 (12:23 UTC; 33.13 N, 99.00E; H = 10 km; Mb = 5.5) during the self-isolation period (http://www.gsras.ru/new/eng/ssd.htm). Figure 9 shows the records of earthquake waveforms on the vertical components of the broadband channel of the three stations concerned, the records are made on the same scale and are presented in a «pure» form (without filtering). For each station, there are the records of two vertical

Figure 7
Signal amplitude fluctuations for the harmonics of 4, 11 and 17 Hz during the periods before and after self-isolation

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channels, there is a record of 2018 earthquake on one of them (top), and the 2020 record—on the other (bottom).

There is a significant level of interference in the records of the 2018 seismic event, which makes it difficult to determine the time of seismic arrivals, as well as to determine the arrivals signs and clarity. This interference almost completely swamps the seismic channel recording, which makes it impossible to process the data without applying the filtration. On the record of the 2020 earthquake, not only surface waves are clearly distinguished, but also P-wave arrivals, the purity of the recording of which directly affects the determination of the earthquake focal mechanism by means of the method of the P wave first-motion polarity (Prytkov et al., 2018). The
almost complete absence of interference suggests, that there is low social activity in the areas where the seismic stations are located.

In order to determine the frequencies, at which the interference occurs, the power spectral density (PSD) of noise and the Fourier amplitude spectrum (FFT) analysis of our earthquakes was carried out (Fig. 10).

From the data obtained, it is seen, that the main source of interference on the seismograms is technogenic noise within the 1–20 Hz frequency band, which is generated by the locality and its industrial facilities.

So, we can conclude that the influence of technogenic noise makes it difficult to isolate and
process the records of seismic events and shows the inexpediency of placing seismic stations in densely populated parts of cities.

4. Conclusion

Continuous records from the seismic stations in three cities of the Russian Far East before and after self-isolation regime were used for analyzing the change in the level of seismic noise. In order to study the noise characteristic, the authors applied the following approaches. The study was carried out using the broad band and short-period seismometers installed at each station.

By constructing noise envelopes and imposing the Yandex self-isolation index on them, we found that the trend of the usual level of social activity on station channel records in the cities before the self-isolation period and during it clearly correlates with the increase in the periods of activity on working days and their decrease on weekends. The channel records clearly show three impulse anomalies, two of which are strong seismic events, and one is an atmospheric phenomenon in the form of a cyclone that have passed over the southern part of the Russian Federation Far East on the studied days and significantly affected the level of noise records.

We have assessed the influence of the technogenic seismic noise, including such a meteorological factor as a cyclone, by means of analysis of the power spectral density of the noise. It was noticed that in the records of short-period seismometers, its effect is not observed at the frequencies below 1 Hz, but it is well manifested at the frequencies of 1–10 Hz, which points to the manifestation of the «cultural» noise. In addition, the smoothed curves have been plotted to assess the social activity of the population in each city during the morning and evening hours. The study of the spectral composition of seismic noise revealed the change in «noisy» working days and «quiet» weekends, the noise density in the frequency range of 1–20 Hz is well traced before the self-isolation period and practically disappears from the beginning of its declaring. Lockdown also left its mark on the quality of seismic events recording. The paper demonstrates the effect of a high noise level on seismogram records using the example of two earthquakes with similar parameters and occurring in the same region two years apart. The decrease of seismic noise in the places, where seismic stations are installed, allows for a better determination of the starting time of the seismic waves arrival.

The results obtained give a hope, that they will be useful for identifying and characterizing the certain sources of the anthropic noise, as well when choosing a place to install the seismic stations in the future. This will allow to significantly improve the earthquakes monitoring.

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Data Availability

The data used in the work were obtained with large-scale research facilities «Seismic infrasound array for monitoring Arctic cryolitozone and continuous seismic monitoring of the Russian Federation, neighbouring territories and the world».

Declarations

Conflict of interest The authors have not disclosed any competing interests.

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