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SHORT-PERIOD SEISMIC NOISE VARIATIONS IN SOUTHERN FINLAND

by

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Abstract

Short-period seismic noise was recorded at 10 places in southern Finland on two days, one windy and the other calm. The records were spectrally analyzed. It was found that the main influence of local weather on microseisms is in the band 0.5–2.0 Hz. Some preliminary conclusions were also drawn about the decrease in amplitude from the shore of the Gulf of Finland to the interior. The predominant sources of artificial seismic noise in southern Finland were verified to be sawmills, which usually work with a frequency of about 6 Hz and disturb the recording of local seismic events for distances of over 10 kilometers from the mills.

1. *Introduction*

A low level of seismic background noise is of great importance to ensure the sensitivity of any seismic station. This noise exists at all the frequencies of interest in the recording of seismic events. By short-period noise is here understood to be any noise that disturbs the records of short-period seismographs, which are usually used to record the first arrivals of waves from distant earthquakes and local seismic events. The frequency band studied here lies therefore between the frequencies of 0.4 and 20 Hz.

Short-period noise has evidently both artificial and natural sources. The artificial noise is, as is well known, produced by traffic and by industry. The main sources of short-period natural noise, or short-period microseisms, are usually suggested to be situated in local sea areas. In addition, there comes the direct influence of wind on buildings or the seismometers, if they are under the open sky.

This work was planned to find out how far from the shores of the seas, busy highways and industrial areas seismograph stations should be situated to avoid local noise or to gain a substantial lowering in the noise level. The records of measured noise were digitalized and subjected to spectral analysis.

2. *Measurements*

Noise measurements were carried out at 10 places in southern Finland. These sites are shown in Figure 1. They are numbered from 1 to 10 from the coast of the Gulf

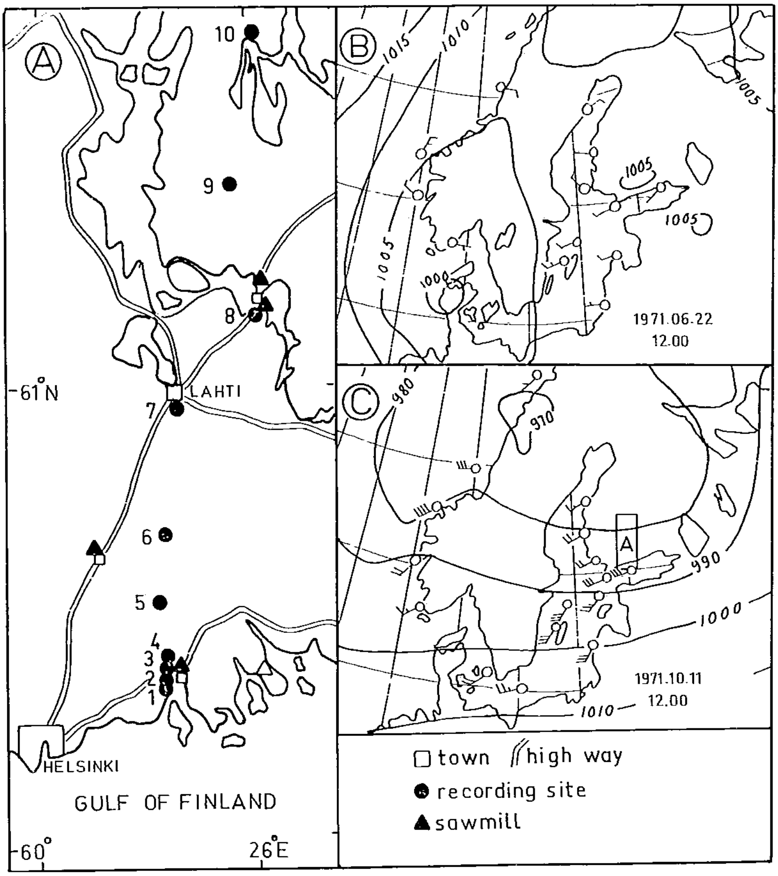

Fig. 1. (A) Locations of the recording sites and noise sources. (B) and (C) The weather situations on June 22 and on October 11, 1971, at 12 o'clock noon together with location of (A).

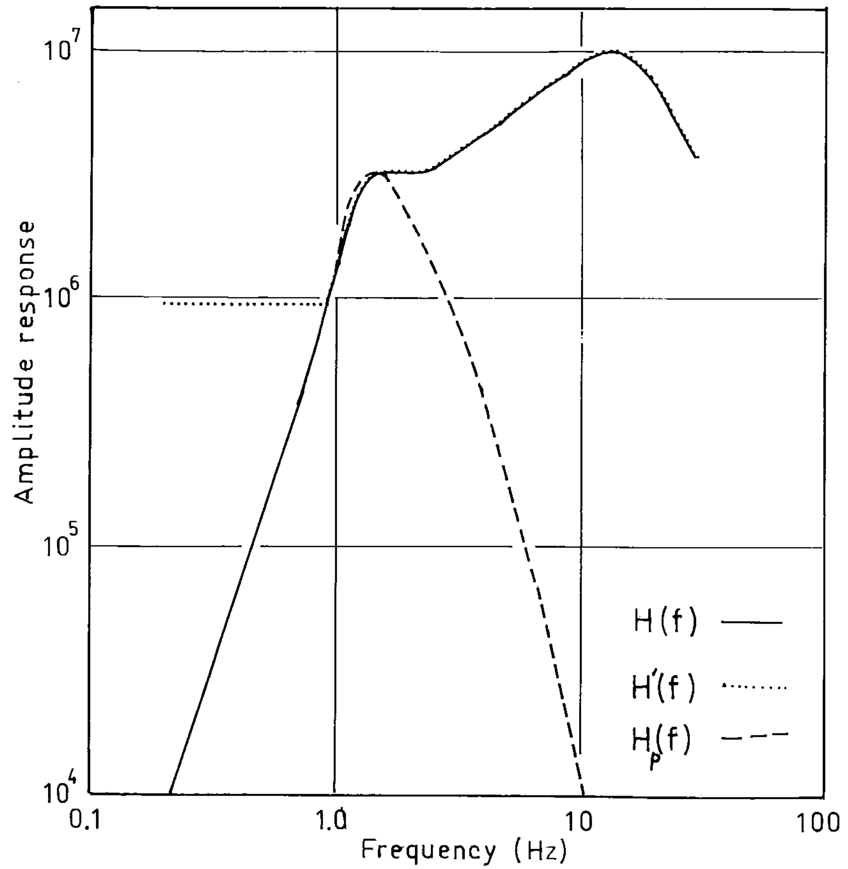

Fig. 2. Amplitude response curves of oscillograph outputs: $H(f)$ response of ordinary records, $H_p(f)$ response of low-pass filtered records and $H'(f)$ a modified response used in correction of periodograms.

of Finland to the interior. The length of the recording line, representing the distance between places 1 and 10, was about 160 km. Each recording site was chosen so that the seismometer could be installed on exposed bedrock rather well protected from the direct influence of the wind.

The seismometer was a Willmore vertical seismometer with a free period of 0.8 seconds and damping of about 0.3. The signals were recorded by a Tandberg tape recorder model TB11 on 1/4-inch tape in analog form. The required amplifier, filtering and modulator units were constructed in the Institute of Seismology, University of Helsinki, by S. NURMINEN [4]. The amplitude response $H(f)$ of the oscillograph output is shown in Figure 2.

The measurements were made moving by car from place to place. A record of about 10 minutes was taken at every site. The whole operation took from 5 to 6 hours. Measurements were made once on June 22 and again on October 11, 1971. Fig. 1 shows the weather conditions for each day at 12 o'clock noon. It is seen that, on the whole, the wind was weak on June 22 in the Baltic Sea. This day is designated here a calm day. On the other hand, on Oct. 11, called here a windy day, the wind blew hard over the Baltic Sea from the SW and almost from the West on the Gulf of Finland. These and other meteorological data for this study come from the Finnish Meteorological Institute.

3. *Spectral analysis*

Visual outputs were obtained from the records by oscillograph. The analogue-to-digital conversion was carried out by means of a semiautomatic digital convertor (P.C.D. type ZAE.2A), which also punched data on paper tape. When the computer program was prepared to get estimates for the power spectra of time series, the ideas and recommendations of COOLEY *et al.* [2] and TUKEY [5] were taken into consideration. The program was written in the Fortran and it operates as follows:

(1) A sequence of $N = 2^M$ numbers is chosen.

(2) The linear trend and mean are removed by least square line fitting.

(3) The sample sequence is tapered over 10 per cent at each end by a cosine bell.

(4) The Fourier coefficients are calculated using the Fast Fourier transform algorithm.

(5) The periodogram is formed as follows:

$$I(f_k) = (a_k^2 + b_k^2)/\Delta f, \qquad k = 0, 1, 2, \ldots, N/2-1$$

where $a_k + ib_k$ is a complex Fourier coefficient and Δf is the frequency difference between adjacent spectral lines.

(6) The periodogram is response corrected by modified amplitude response function $H'(f)$ (Fig. 2), which is identical with the true amplitude response $H(f)$ in the range of main sensitivity but is kept constant on the 10 %-level of the peak magnification for low frequencies. This modification is made because $I(f)$ at the lowest frequencies represent noise resulting from the method rather than real microseisms. The same 10 %-level of peak magnification had been used earlier by BERCKHEMER *et al.* [1].

(7) To arrive at a better estimate of the power spectral density, the periodogram is smoothed by taking weighted averages of successive values. The length of the weighting function was determined experimentally, so that reasonable stability was achieved.

4. *Results and discussion*

First 10 second lengths of the records were spectrally analyzed. Owing to the sampling rate of 51.2 samples per second, sequences of 512 numbers were produced. For smoothing, the weighted averages of 17 neighbouring spectral lines were taken. A set of triangular weights $W(k)$ was used, so that

$$W(k) = k/N^2,$$

where $k = 1, 2, \ldots, N, \ldots, 2, 1$ and $N = 9$.

In Fig. 3A are shown some spectra of noise recorded on June 22. Every fifth spectral line has been printed out. The distances to the nearest industrial area from the stations is also indicated in the figure. It is seen that there is more than a 20 dB difference in the noise level at the high frequency end between the spectra of noise recorded at stations 1 and 10. On the other hand, site 6 is almost as quiet as site 10. The difference of about 6 dB in the frequency band from 3 to 7 Hz is caused perhaps by traffic on the Helsinki–Lahti road, which is at a distance of 12 kilometers from station 6 where there is much traffic. Note also the high broad band peak on the same frequency band in the noise spectra of station 7, which stood at a distance of 1 km from a road with very busy traffic; hence a continuous sound of traffic was heard at the station. The great noise peak sligthly below 14 Hz at site 1, caused by a nearby cellulose mill or by work at a dock, was strictly local and therefore not very interesting.

The predominant peaks at about 6 Hz are caused by sawmills. In Fig. 3B, peaks caused by sawmills in the spectra of noise recorded on June 22 and Oct. 11 are presented separately. The distances from the recording sites to the nearest sawmill are also indicated in the figure. A clear correlation, even if not quite systematic, appears between the height of the peaks and the distances. The sawmills, which caused the noises, were not the same either. In addition, the noise caused by a sawmill depends also on how heavy are the sawn goods. Therefore the level of noise also varies at the same place from time to time. In the spectrum of noise at station 1 on October 11, the peak of 6 Hz is missing altogether. The recording was made during lunchtime at the sawmill.

Next, the spectra of the microseisms on the windy day and on the calm day will be compared. Fig. 4 gives an example of the spectra of three stations from both days. The differences in the spectra of the same station are seen to be largest at low frequencies. It is therefore evident that the weather has its main effect on the low frequency end of the spectrum when it is kept mind that the direct effect of the wind on the seismometers was mainly hindered. From the periodograms were also calculated the spectra for the low-frequency ends, smooth-

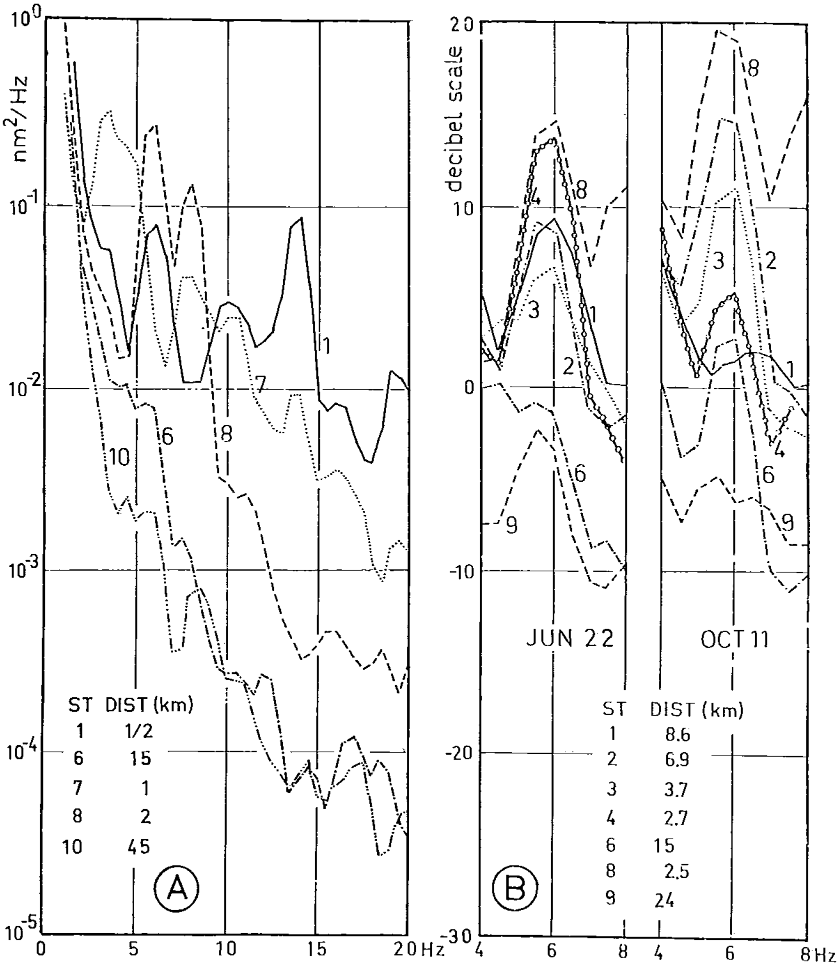

Fig. 3. (A) Spectra of noise at stations 1, 6, 7, 8 and 10 on June 22, and the distances to the nearest industrial area. (B) Spectral peaks caused by sawmills in the spectra of noise on June 22 and October 11, and the distances to the mills from the recording sites.

ing only with the triangle weights of seven points. Examples of these curves are shown in Fig. 5A. From each pair (10 pairs) of spectra, the differences were measured and the means calculated. These values are shown in Fig. 5B. The wind is seen to have its main effect at about 1 Hz (over 13 dB in this case). At frequencies higher than 2 Hz, the effect of the wind is small, under 4 dB.

To obtain more information on the effect of the weather on short-period microseisms, the high-frequency part was removed from the records of October 11 with

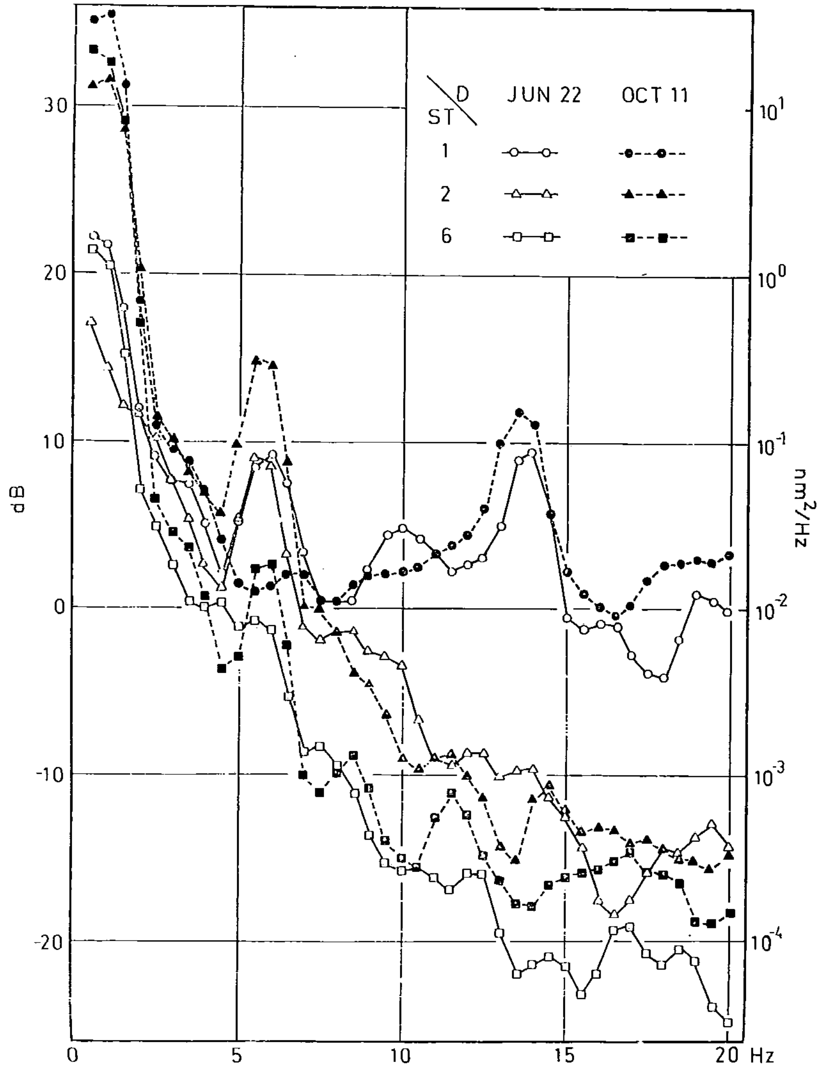

Fig. 4. Spectra of noise recorded at stations 1, 2 and 6 on June 22 and October 11, 1971.

a 2-Hz low-pass filter (see Fig. 2). From the new visible records, 100-second lengths were digitalized with a sampling frequency of about 5 Hz. The spectra were now calculated without response correction and the periodograms smoothed by forming moving averages over 17 successive values. Every fifth spectral line was printed out. Some of these spectra are shown in Fig. 6. The original long-period microseisms

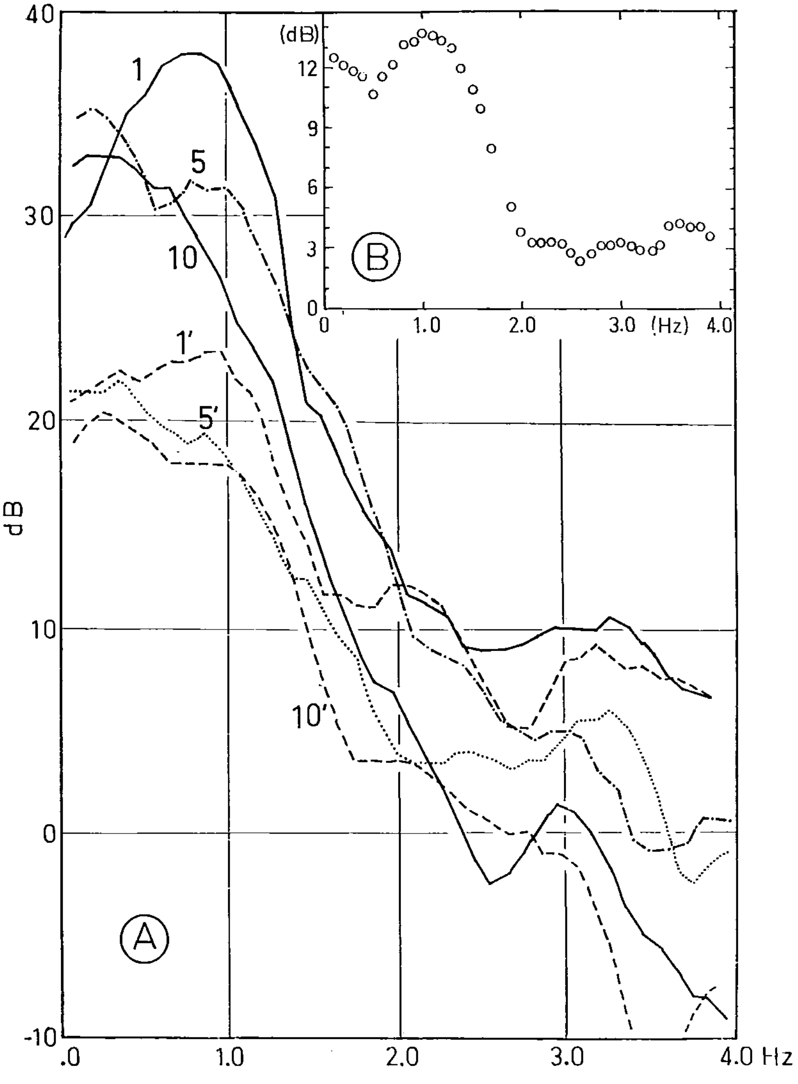

Fig. 5. (A) Low-frequency parts of the spectra from stations 1, 5 and 10, taken from the records of October 11 (numbers without apostrophes) and June 22 (numbers with apostrophes). (B) Average difference between spectra of October 11 and June 22 calculated from all 10 pairs of spectra.

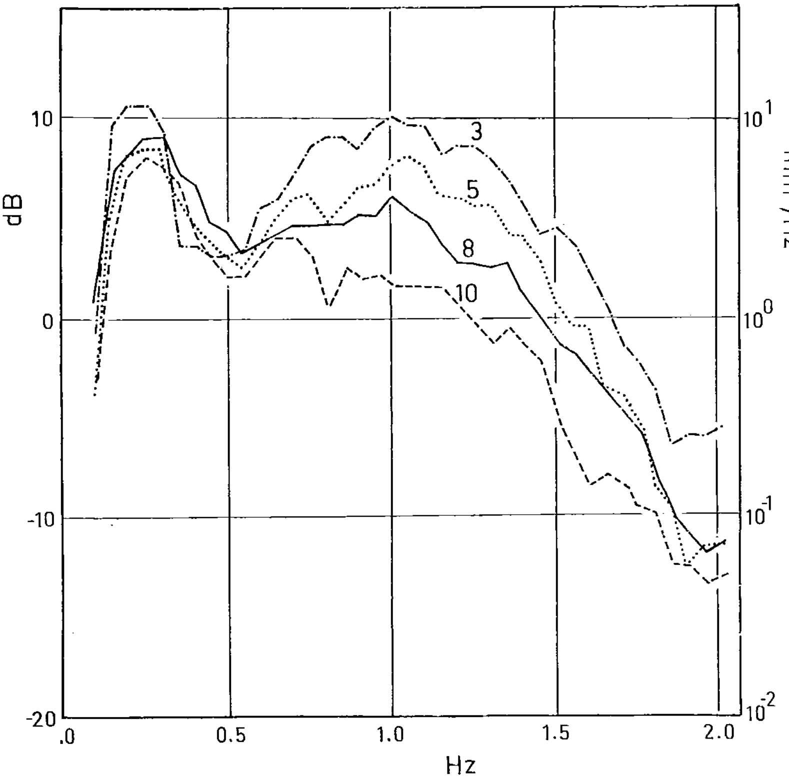

Fig. 6. Trace spectra calculated from low-pass filtered records on October 11 from stations 3, 5, 8 and 10.

now appear clearly in the low-frequency part in spite of the very low seismograph magnification at these frequencies. The noise level there was almost the same in the different parts of the recording line. On the other hand, the short-period microseisms, in the frequency band of about 0.5–1.7 Hz, show a clear tendency to fall lower from the shore toward the interior suggesting that they are generated by local sea waves. However, the spectra of the first four stations did not show any appreciable differences, which means that the source of the microseisms was not near the end of the recording line at the Gulf of Finland. According to the weather data (see Fig. 1), the largest sea waves were evidently in the northern part of the Baltic Sea and at the eastern end of the Gulf of Finland, which were thus the most obvious sources of short-period microseisms.

The short-period noise in the region is clearly divided into two parts in the frequency domain, so that the natural microseisms are located in the low-frequency part, below 2 Hz, and the artificial noise in the high frequency part of the spectrum. The artificial noise has a great disturbing effect on the recording of local seismic events. The seismograph stations should be located at a distance of at least 10 kilometers from industrial areas and major highways. Especially troublesome are sawmills, which work at frequencies ranging from 5 to 7 Hz, usually at 350 cycles per minute. A remarkable noise peak of 5.7 Hz has also been found by KORHONEN and KUKKONEN [3] in the short-period noise recorded near the city of Oulu in northern Finland and explained as caused by a sawmill. On the other hand, remarkable noise peaks found by them in the band of 2–3 Hz and attributed to waterpower plants are not found in the region studied here. The short-period natural noise, which reaches its maximum at about 1 Hz in a meteorological situation like that on October 11 is troublesome, especially in recording body waves from teleseismic events. This noise is much more difficult to avoid than the industrial noise. A distinct advantage is achieved when seismograph stations are located at least 150 kilometers away from the shores of the Baltic Sea or its gulfs.

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