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VI.4 Seismic noise at high frequencies

Our program for noise measurements in and around the NORSAR siting area, reported upon also in previous Semiannual Reports, has continued in the following way:

- All NORSAR subarrays have been visited with Kinemetrics PDR-2 equipment, 'tapping' the data between the amplifier and the anti-aliasing filter. The sampling rate mostly used has been 62.5 Hz with filter at 25 Hz, but some data have also been recorded with a 125 Hz rate and filter at 50 Hz. This system has an excellent dynamic resolution up to at least 40 Hz.
- The present NORESS area (subarray 06C) has been studied in greater detail (PDR-2 recordings), using both standard 06C sensors and the temporary NORESS sites. Time-of-day variations have also been studied here. Excellent dynamic resolution.
- Data transmitted in analog form to NORSAR from 06C and 02B have also been analyzed, the sampling rate here is 40 Hz, but the dynamic resolution is poor, and there is an increasing amount of system noise from the telephone lines for frequencies above 2-3 Hz.
- Noise data from a 60 m hole have been recorded simultaneously with surface data (using the PDR-2), and comparisons are made under various conditions. Excellent dynamic resolution.
- Six other sites in southeastern Norway have been studied by 'tapping' (using the PDR-2) the analog (telephone) lines from the Southern Norway Seismic Network (SNSN). System noise is a problem also here.

Representative noise spectra from 6 NORSAR subarrays (except 06C) are shown in Figures VI.4.1-2, with recordings using the Kinemetrics PDR-2 on the output from the NORSAR RA-5 amplifiers in the Central Terminal Vault (CTV) of each subarray. This corresponds to System No. 12 in Table III.4.1 of this report, where it is seen that the PDR-2 gives a gain of 42 dB (for the weakest signals) in addition to the 72 dB from the

NORSAR amplifier. The recordings have been done with a sampling rate of 62.5 Hz (16 ms sampling interval) and with an anti-aliasing filter (12 dB/oct) at 25 Hz. The spectra in Figs. VI.4.1-2 cover various parts of the winter from day 337/1982 to day 56/1983 and should therefore be expected to cover generally high noise levels for frequencies below 2 Hz. The 1 Hz levels for the cases shown is between 5 and 10 dB above 1 nm^2/Hz, while we previously have shown that the typical summer level is more in the range 0 to 7 dB. The spectra in Figs. VI.4.1-2 show typical noise levels for each subarray, and it is easily seen that they are strikingly similar (above 2 Hz), with a 10 Hz level at -50 dB below 1 nm^2/Hz. The only exceptional feature in these spectra is a strong 12.5 Hz noise peak from 02C00, that one is caused by inductive interference from a 50 Hz power line close to the analog tranmission line from seismometer to CTV.

From Figs. VI.4.1-2 we can also see for most of the channels some spectral flattening above 15-20 Hz. This is caused by various cultural activities at close distances, and is quite often much more prominent than shown here, sometimes also starting at frequencies as low as 5 Hz. There is a clear correlation between these observations and the population density in the vicinity of each of the subarrays.

Data recorded with a sampling rate of 125 Hz and an anti-aliasing filter at 50 Hz have also been analyzed, as shown in Fig. VI.4.3 for subarrays 02B and 06C (NORESS). It is seen there that the ambient noise level continues to drop at about the same rate all the way up to 50 Hz (provided that cultural noise sources can be avoided), a rate which is close to 15 dB/octave or 50 dB/decade. It is seen that the lowest noise level resolved here is about -80 dB relative to nm^2/Hz, or 260 dB below 1 nm^2/Hz, which is 5 dB below Herrin's (1982) lowest value for Lajitas. The spectral differences between the two sensors in Fig. VI.4.3 are typical, in the sense that subarray 02B is somewhat less affected by cultural noise at high frequencies than 06C, which is the present NORESS site.

Because of the possibility that the 06C area could be chosen as the site also for the permanent NORESS installation, fairly extensive noise surveys have been conducted there. As a part of that, we have covered the area with regular PDR-2 recordings throughout the day and night, and Fig. VI.4.4 shows here an example for 1400, 1800 and 2200 GMT. In addition to the general decrease in the noise level above 5 Hz by night, there is also a prominent and fairly broad peak around 5.5-6.0 Hz which also disappears by night. This peak can also be seen in several of the spectra presented above, and we have come to the conclusion that it probably is caused by the integrated effect of all the traffic in the general area. The survey has moreover shown that the 06C (NORESS) area is at times significantly affected by local cultural noise sources above 5-10 Hz, and much of this comes from lumbering and other economic activities within the immediate vicinity (< 5 km) of the sites. In this sense, both subarray 02B and 03C (which both could be acceptable as NORESS sites from a signal focusing point of view) are somewhat better than 06C, but the difference is not very clear and all seven subarray sites are at times significantly affected by high-frequency cultural noise from sources at short distances.

All the seismic noise spectra presented above have been taken from surface installations (i.e., 2-5 m borehole depths). In order to test the possible gain from deeper borehole installations we have conducted some simultaneous PDR-2 recordings from surface and 60 m deep seismometers at site 01A01, with results as shown in Fig. VI.4.5. It is seen there that the difference starts at around 8 Hz and increases to more than 10 dB for frequencies above 20 Hz. However, in comparing with the 02B and 06C spectra in Fig. VI.4.3 we see that those spectra are closer to the 01A 60 m spectra in Fig. VI.4.5, and we should therefore not expect a gain of this size for sites that are less affected by local cultural noise than 01A. For technical reasons, we have so far not been able to investigate the noise reduction potential for other depths than 60 m.

Seismic noise spectra from 3-component recordings done at subarray 06C are shown in Fig. VI.4.6, using SS-1 seismometers and the usual PDR-2 recorder. The results show that there is no systematic difference between vertical and horizontal components for frequencies above 3-4 Hz, while for lower frequencies the noise level on the vertical component is slightly higher.

We have, in addition to the detailed noise studies from various NORSAR installation, also analyzed data from the Southern Norway Seismic Network (SNSN), in this case also using the PDR-2 recorder in combination with significantly preamplified signals. The results clearly confirm our conclusions from above with respect to the stability of the noise spectra for higher frequencies. However, the data are somewhat affected by transmission noise on the telephone lines used, a problem which also affects our present analog data channels from subarrays 02B and 06C, for frequencies above 2-3 Hz.

In order to facilitate the comparison between a typical NORSAR (or southeastern Norway) noise spectrum and previously published quiet sites, we have in Fig. VI.4.7 plotted our results as presented above on top of the Queen Creek and Lajitas noise spectra (Herrin, 1982). We see from that figure that there is not much difference between these spectra for higher frequencies, and this makes it natural to ask the question if there actually is a fairly stable and uniform ambient noise level globally for these frequencies. In fact, since southeastern Norway and Lajitas (Texas) are so similar (as shown in Fig. VI.4.7), there are no reasons to believe that other areas of the world should be significantly different (provided, of course, that local cultural noise sources can be avoided).

In conclusion, we have found that:

1) The ambient seismic noise level above 2-3 Hz in southeastern Norway is very stable both in time and space. The level at 10 Hz

is always very close to -50 dB relative to 1 nm^2/Hz, with a slope in the 5 to 40 Hz range of 15 dB/octave (50 dB/decade). Levels down to 10^{-8} nm^2/Hz (-80 dB) have been resolved.

2) There is, for all of the sites studied, a problem with cultural noise for frequencies above 5 Hz, and this problem increases with increasing frequency. There is a rush-hour peak around 5.5-6.0 Hz, while the cultural noise above 10 Hz sometimes consists of a broad-band contribution (many sources at various distances) but more often of narrow spectral lines (few and close-in sources). This problem, however, is manageable if careful site surveys are executed.

3) Another prominent cultural noise source consists of inductive interference from nearby 50 Hz power lines, and this often gives significant contributions, especially at 12.5 Hz. We know that most of this interference comes from the cables, but we cannot exclude the possibility of some interference also in the seismometer itself if the distance to the power line is small.

4) In comparing the seven subarrays at NORSAR, we find that this 50 Hz (12.5 Hz) noise problem is particularly serious for subarrays 01B and 02C. Subarray 01A is problematic with respect to other cultural noise sources and to some extent also 06C (the present NORESS site), while subarrays 02B, 03C and 04C are somewhat better in this respect, even though these too are somewhat affected by the same problem. This relative rating is consistent with what we should expect from merely looking at the population density and the network of roads in the area.

5) The local cultural noise for frequencies above 8 Hz can be reduced considerably by using 60 m deep boreholes, but we do not know the noise reduction potential for other depths. Wind noise is a small problem in this respect, partly because there usually is very little wind in the area, and partly because most of the wind noise can be

avoided simply by cutting trees near the site and by installing the seismometer at a few meters depth in competent (crystalline) rocks.

6) For higher frequencies there is no systematic difference between vertical and horizontal components.

7) In comparing with so-called 'extremely quiet' sites in other continents (notably Lajitas in Texas) we find that the noise levels there for frequencies above about 10 Hz are quite close to what we find for southeastern Norway. The possibility therefore exists that the ambient noise level that we have found for southeastern Norway, with its stability in time and space, in fact could be a globally representative noise level.

H. Bungum

<u>Reference</u>

Herrin, E.T. (1982): The resolution of seismic instruments used in treaty verification research. Bull. Seism. Soc. Am. 72, S61-S67.

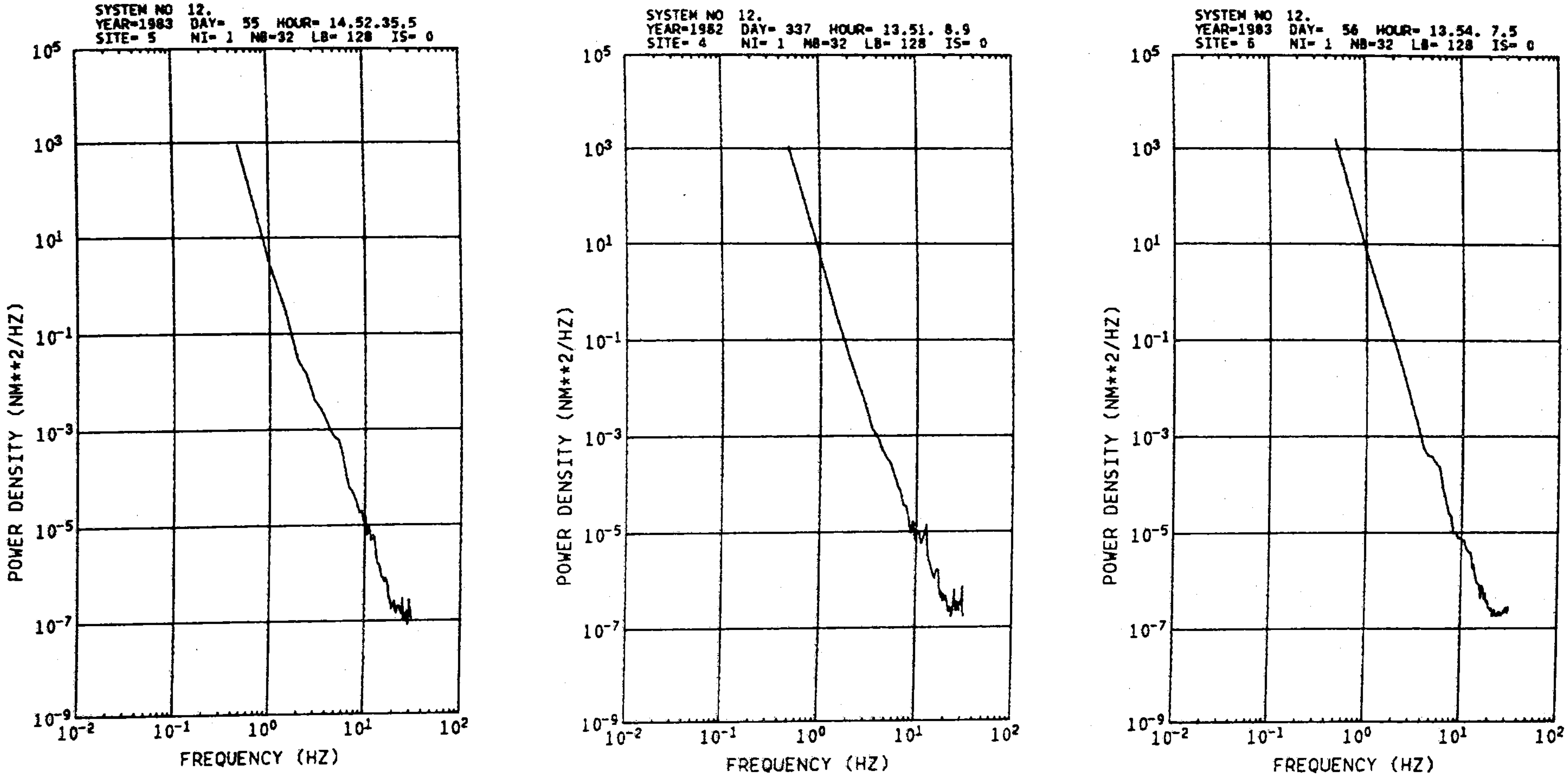

Fig. VI.4.1 Noise power spectra (PDR-2 recording at 62.5 Hz) for NORSAR site 01A05 (left, day 55/1983), 01B04 (center, day 337/1982), and 02B00 (right, day 56/1983). All are day-time spectra.

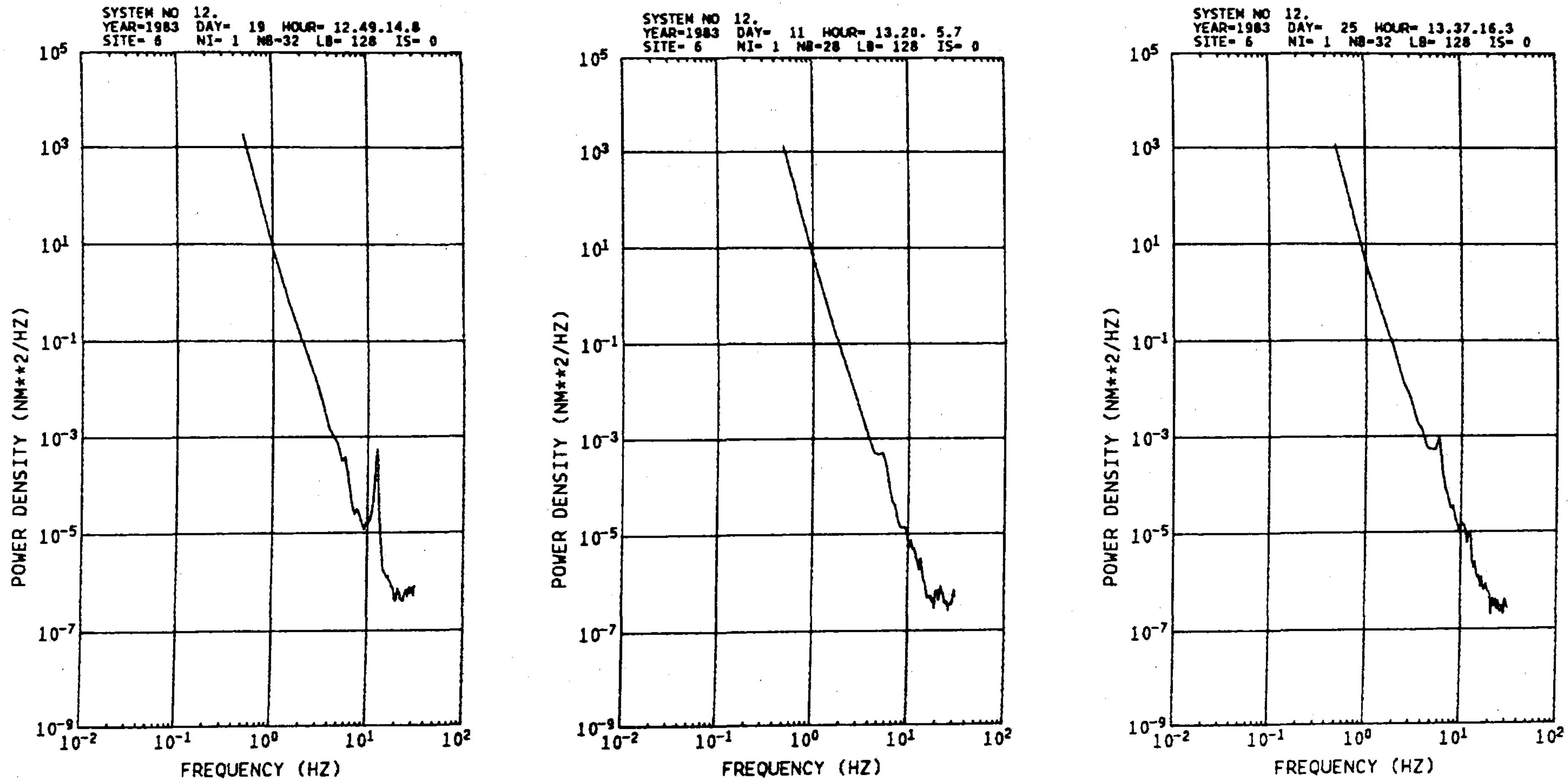

Fig. VI.4.2 Noise power spectra (PDR-2 recording at 62.5 Hz) for NORSAR site 02C00 (left, day 19/1983), 03C00 (center, day 11/1983), and 04C00 (right, dat 25/1982). All are day-time spectra.

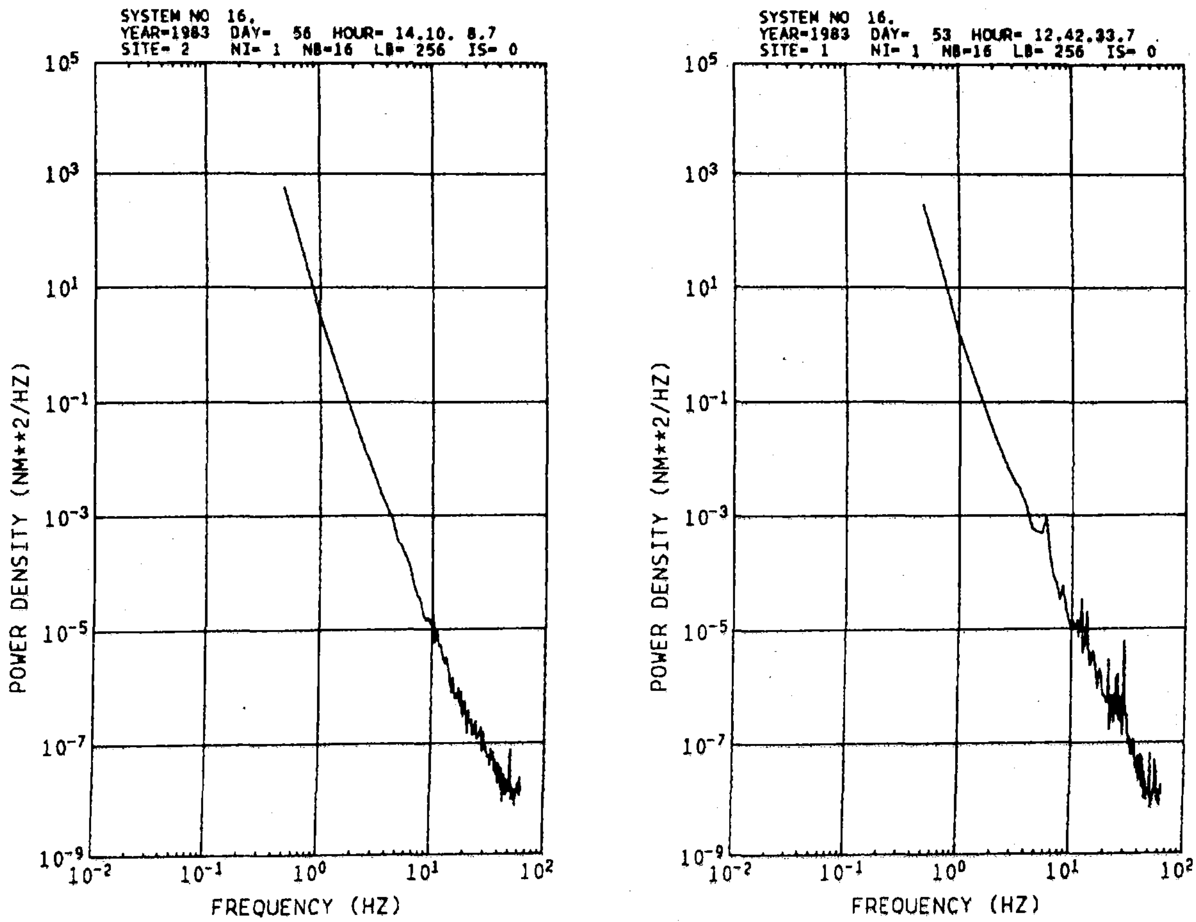

Fig. VI.4.3 Noise power spectra (PDR-2 recording at 125 Hz) for NORSAR site 02B00 (left, day 56/1983) and 06C02 (right, day 53/1983). Both are day-time spectra.

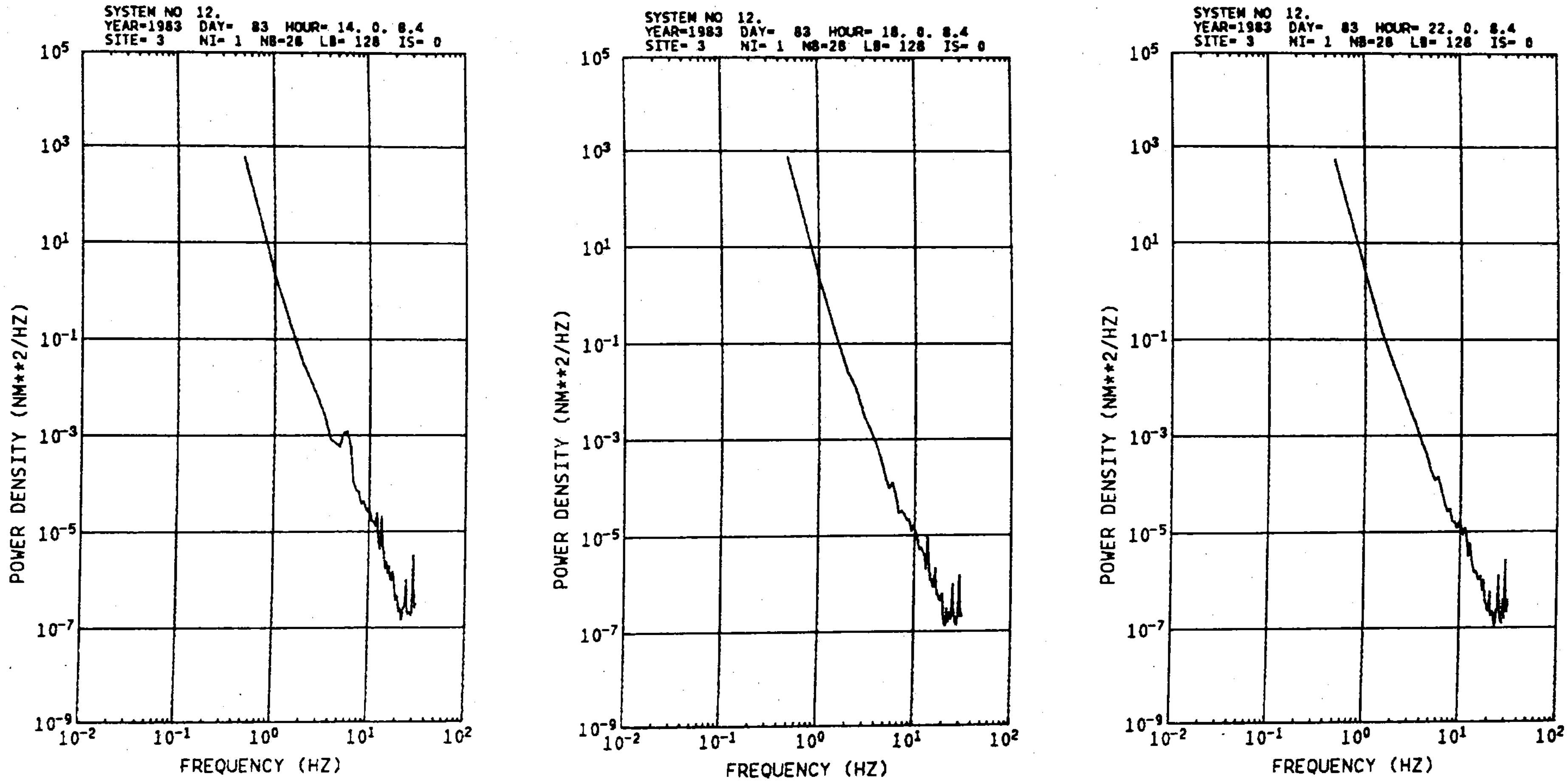

Fig. VI.4.4 Noise power spectra (PDR-2 recording at 62.5 Hz) for NORESS Site 8 (close to 06C02) from day 83/1983 at 1400, 1800 and 2200 GMT.

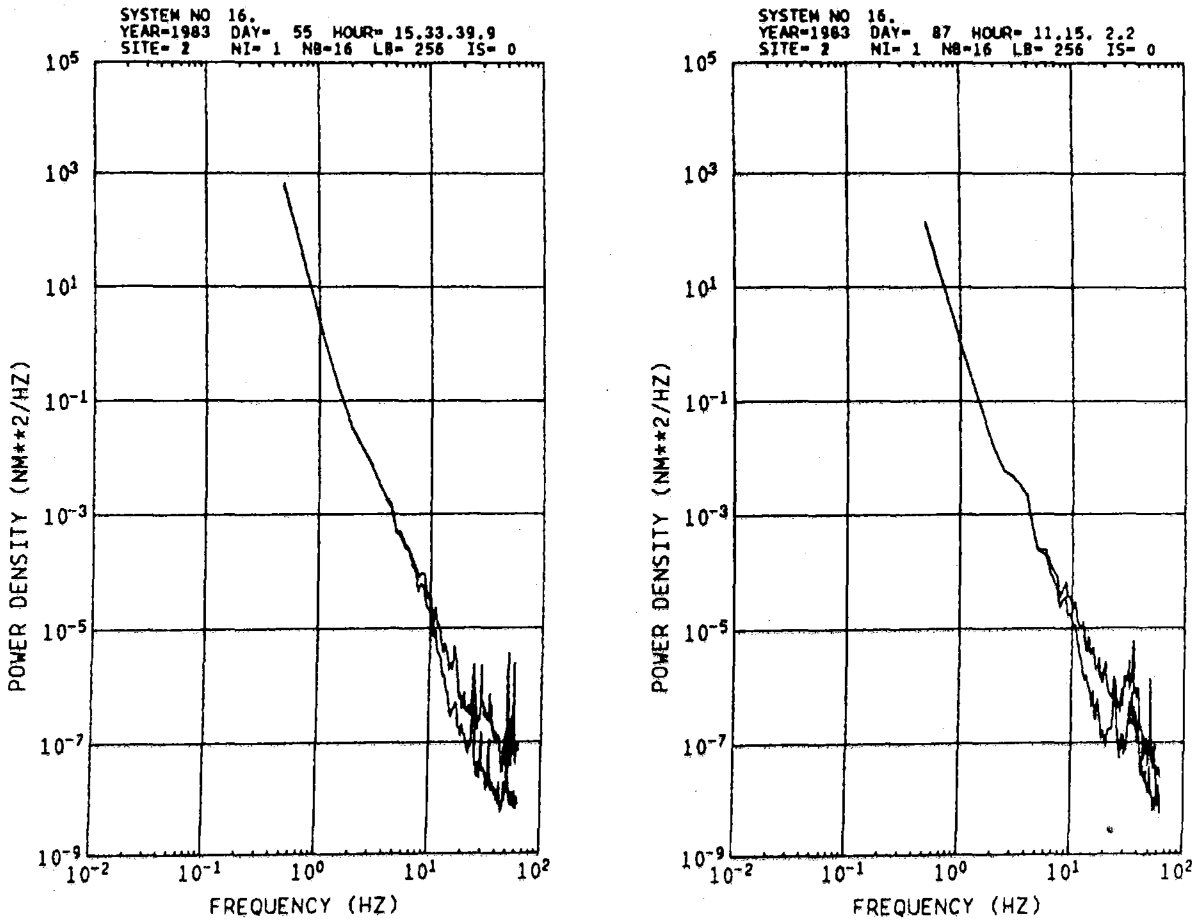

Fig. VI.4.5 Noise power spectra (PDR-2 recording at 125 Hz) for NORSAR Site 01A01 and from a 60 m borehole at the same site, at two different times (day 55/1983 and day 87/1983).

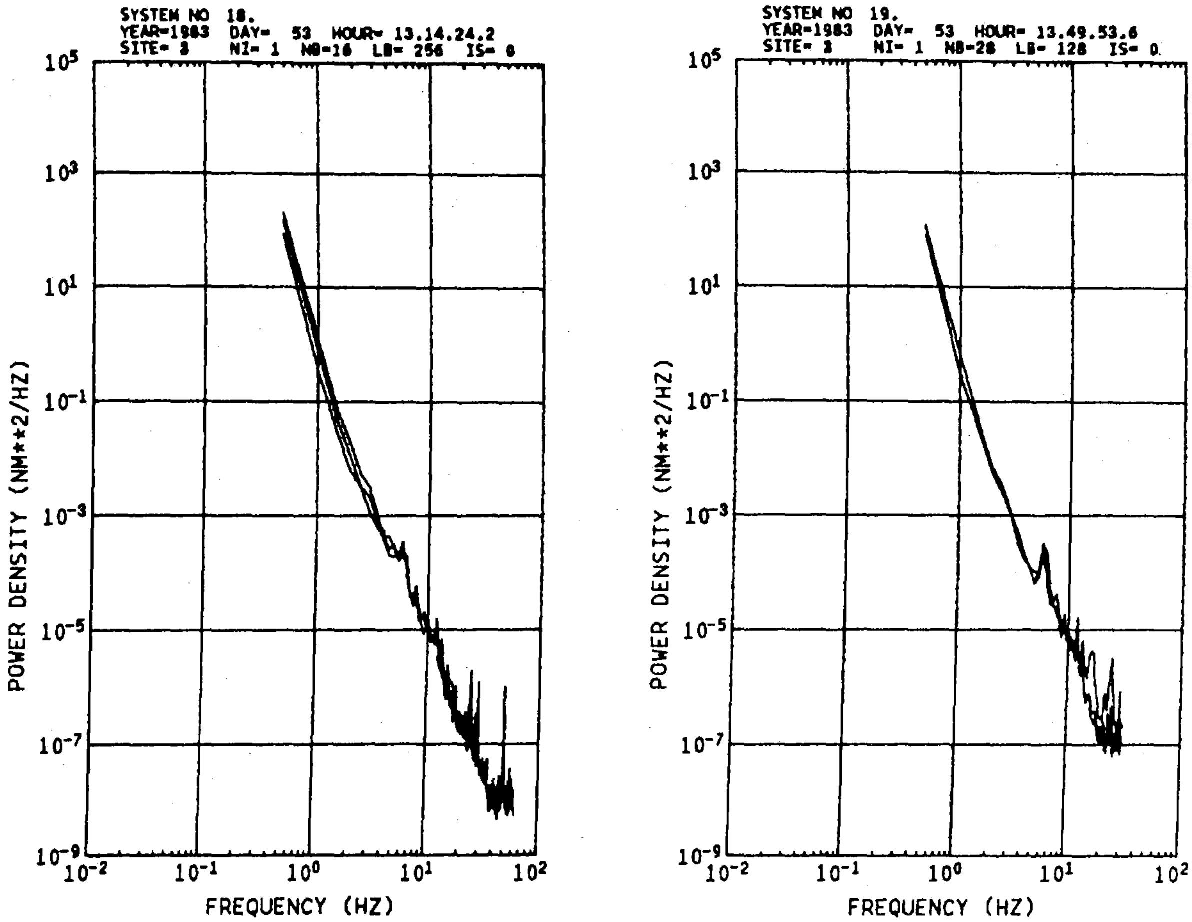

Fig. VI.4.6 Noise power spectra (PDR-2 recording) for NORSAR Site 06C02, using 3-component SS-1 seismometers, day 53/1983. Both are day-time spectra, left: 1314 GMT, 125 Hz recording; right: 1349 GMT, 62.5 Hz recording.

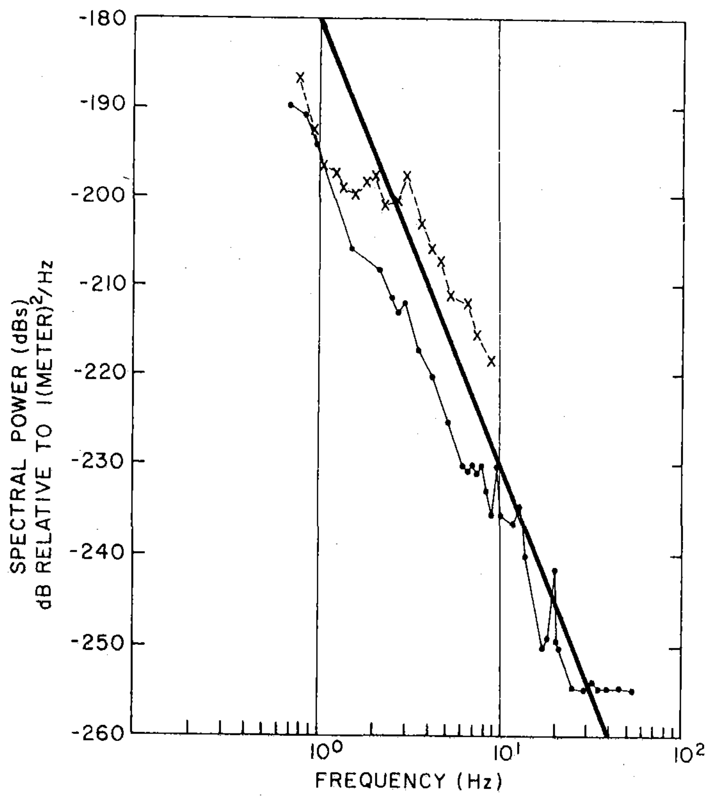

Fig. VI.4.7 Noise power spectra for 1) Lajitas (dots), 2) Queen Creek (x's) and 3) southeastern Norway (heavy line). 1) and 2) are taken from Herrin (1982) while 3) is a typical average for the data presented in this study (for frequencies above 2 Hz).