NORSAR ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 2 - 81/82

SEMIANNUAL TECHNICAL SUMMARY

1 October 1981—31 March 1982

By
Jørgen Torstveit (ed.)

Kjeller, July 1982

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 2551

VI.7 Fennoscandian noise survey

During the summer and fall of 1981, the first part of a noise study was performed involving various sites in Finland, in northern Norway (Finmark), and in southeastern Norway. The purpose of this survey, which still continues, is to measure the ambient noise level as a function of frequency for various sites in Fennoscandia, and to measure noise correlation as a function of short interstation distances for some of these sites. Special emphasis has been given to high frequencies, in order to obtain information relevant to the construction and possible deployment of small aperture seismic arrays aimed at detection and analysis of regional seismic signals.

Recording equipment and logistics

The main field equipment used has been Kinemetrics PDR-2 'Compuseis' recorders combined with Geotech S-13 seismometers, and preamplifiers were needed in order to obtain sufficient amplitude resolution for the background noise. The data were recorded on cassettes and subsequently played back using a Kinemetrics CCS-1 playback system and an IBM 4341 computer. A much faster playback procedure was later developed based on a PDP 11/34 computer, and the development of these programs was an effort that was completed late spring 1982.

In addition to the data recorded by the PDR-2 field recorders, the noise study has also included some 40 Hz NORESS data recorded at the NORSAR data center. These data, from 8 of the NORESS seismometers, have been transmitted in analog form to Kjeller and recorded there via the new MODCOMP/IBM 4331 connection.

Methods of analysis

The procedure for computing power spectra depends on the nature of the data under analysis. Basically, these would fall into three main categories:

a) Transient signals:
   The Energy Density is estimated as

$$P_x(f) = \Delta t^2 X(f)\overline{X(f)} \qquad (nm^2/Hz^2)$$

where $$X(f) = \sum_{n=0}^{N-1} x(n)\exp(-2\pi i f n/N)$$

Δt = sampling interval (sec)

N = number of samples

b) Stationary signals (noise):

The Power Density is estimated as

$$P_x(f) = \frac{\Delta t}{N} X(f)\overline{X(f)} \qquad (nm^2/Hz)$$

or with block averaging (M blocks)

$$P_x(f) = \frac{\Delta t}{N \cdot M} \sum_{j=1}^{M} X_j(f)\overline{X_j(f)}$$

c) Periodic signals:

The Power is estimated as

$$P_x(f) = \frac{1}{N^2} X(f)\overline{X(f)} \qquad (nm^2)$$

It is the definition under b) which has been used in the present case, for analysis of stationary noise, while a) would be required for analysis of earthquake or explosion signals. Needless to say, the normalization procedure is important when faced with the problem of computing spectra with reference to absolute ground motion.

Noise correlation ρ (zero lag only) has been computed using the same block lengths as for the spectral estimates and averaged over the same number of blocks. The estimates are considered only as functions of interstation distances (azimuth not used), and averages have been computed over certain distance intervals. Since correlations are bounded by unity, they are not normally distributed and standard deviations can therefore not be computed the conventional way. This problem was solved by transforming the correlations into a new variable:

$$z = \frac{1}{2}\left[\ln(1+\rho)-\ln(1-\rho)\right]$$

which will be almost normally distributed as shown by Fisher. Confidence limits are then taken as $z = \bar{z}+\sigma_z$ and $z = \bar{z}-\sigma_z$, and the corresponding levels in ρ are found by the transformation:

$$\rho = \tanh(z)$$

Results

The sites which have been analyzed so far are shown in Fig. VI.7.1 and their names and locations are listed in Table VI.7.1, where also the main results in terms of spectral levels are given. For most of the locations at least 2 time intervals are presented, with results given for 7 frequencies, each separated by one octave.

It should be noted here that for all of the locations from 1 to 7, where the PDR-2 field equipment was used, there was a considerable problem in finding time intervals that were not contaminated by high frequency noise of more transient nature. The sources here were mostly of cultural origin, but also in some cases wind and effects due to poor coupling between seismometer and ground (for many of the sites the seismometers were placed on surface exposure of rock). This problem is of course connected to the fact that we are interested in very low levels of the the ambient noise (down to 0.01 nm) and at frequencies much higher than with more conventional seismometers (sampling rate 62.5 Hz, high-cut filter at 25 Hz). For the future measurements we will counter this problem by more careful siting, concrete pads for the seismometers, wind protection, etc.

In addition to the first sites listed in Table VI.7.1, where the PDR-2 equipment was used, we have also analyzed some intervals of 40 Hz NORESS data as mentioned above. The reason why the results there are given only up to 4 Hz is that the linearly ranged quantum unit for that temporary system is too large to give sufficient amplitude resolution for higher frequencies.

Among the conclusions that can be drawn from the spectral results are the following:

1) The spectral level at 1 Hz is for most sites in the range between 0 and 10 dB relative to 1 nm^2/Hz. Although this is 10-20 dB higher than the SRO/ASRO low noise points (Peterson, 1980) and the Queen Creek level (Fix, 1972), it is still a reasonably good level as compared to most seismic stations of the world.

2) The slope of the spectrum falls off with about 20 dB/octave from 0.25 Hz and up to 1.5-2.0 Hz; above that frequency the slope is around 10 dB/octave all the way up to 16 Hz (see also Fig. VI.7.2). This is contrary to the stronger reduction in slope which is commonly observed for frequencies above about 5 Hz. We have confidence in our results here, however, since i) our use of preamplifier asures a good quantification for the noise, and ii) the high cut-off filter and sampling frequency gives a good relative response at these higher frequencies (see Fig. VI.7.3).

3) The noise level at 0.25 Hz (which is the location of the well-known microseismic peak) shows much stronger variation in time than in space. It is clear that the noise level up to at least 1 Hz correlates (although with much smaller fluctuations) with these 4-second microseisms, which are mostly attributed to atmospheric disturbances over oceans. This is consistent with the change in spectral slope around 2 Hz which could indicate two separate noise processes (Adair, 1982), and it is also consistent with the results of Ringdal and Bungum (1977) who studied long-term noise variation within different frequency bands at NORSAR.

4) Although there is a tendency (as expected) that the Finnish sites get quieter as one moves eastward, the noise levels there are not significantly better than those observed in southeastern Norway. The northern Norway sites, on the other hand, seem to be slightly higher in noise level, which should be expected from the proximity of these sites to the offshore noise-generating areas.

5) For most of the noise data analyzed so far, there is no significant difference between vertical and horizontal components. In a few cases, however, the horizontal components show a slightly higher noise level.

Results in terms of noise correlation are presented in Figs. VI.7.4-6, where Fig. VI.7.4 is from location 7, covering distances from 50 to 600 m. The scatter in the results is fairly large, which in part is due to the fact that the data are taken from non-simultaneous measurements (3 seismometers were successively moved around to 12 sites), and in part caused by the previously mentioned high-frequency transient noise disturbances. There are clear indications in Fig. VI.7.4 that negative correlation occurs at certain distances (dependent on frequency bands), which was shown by Mykkeltveit et al (1982) to be consistent with a model of propagating noise under isotropic conditions.

Correlation results from the NORESS array sampled at 40 Hz are shown in Figs. VI.7.5-6, where the confidence limits now are much smaller. The tendency for the noise to correlate negatively is now even clearer, although the negative deflection is not as pronounced as in the 20 Hz NORESS results presented by Mykkeltveit et al (1982).

The examples in Figs. VI.7.5-6 are picked out so as to show a large difference in correlation levels in the first frequency band (1-3 Hz). It is interesting to note that although there may be a small difference also in the 2-3 Hz band, there is no difference for higher frequencies. It seems therefore that the main correlation variations tend to occur within the frequency band covered by the steepest part of the spectrum (up to 1.5-2.0 Hz), which again point towards different noise processes below and above this frequency.

There is another interesting observation in the fact that the data used in Fig. VI.7.5 (day 80/1982) and in Fig. VI.7.6 (day 130/1982) have reasonably similar spectra (see Table VI.7.1), in spite of very different correlation levels. There is, however, a difference in the sense that the spectrum for day 80 (Fig. VI.7.5) peaks at a higher frequency than for day 130 (Fig. VI.7.6). This points towards a smaller distance to the main noise generation area and possibly shallower water if ocean-generated (cf. Bungum et al, 1971). In fact, the 1-3 Hz noise correlation on day 80 is higher than for any of the other NORESS intervals included in Table VI.7.1, which all fall between the levels of days 80 and 130. It should be mentioned here that some correlation measurements obtained at location 4 are consistent with the results presented above.

The main conclusion in terms of noise correlation is therefore that there is a fairly good stability in time and space for frequencies above about 2 Hz, while there is some variation in time for lower frequencies. This variation correlates more with the shape of the noise spectrum than with the absolute level, pointing towards differences in the noise-generating areas as the main factor of influence with respect to the correlation properties of the noise.

H. Bungum

References

Adair, R., J. Orcutt and T.H. Jordan, 1982: The Marine Seismic System: signals and noise. DARPA Symposium on seismic detection, analysis, discrimination and yield estimation. Hampton, Va., 25-27 May 1982.

Bungum, H., E. Rygg and L. Bruland, 1971: Short-period seismic noise structure at the Norwegian Seismic Array. Bull. Seism. Soc. Am., 61, 357-373.

Fix, J.E., 1972: Ambient earth motion in the period range from 0.1 to 2560 sec. Bull. Seism. Soc. Am., 62, 1753-1760.

Mykkeltveit, S., K. Åstebøl, D.J. Doornbos and E.S. Husebye, 1982: Seismic array configuration optimization. Submitted to Bull. Seism. Soc. Am.

Peterson, J., 1980: Preliminary observations of noise spectra at the SRO and ASRO stations. USGS Open File Report 80-992, Albuquerque, New Mexico.

Ringdal, F. and H. Bungum, 1977: Noise level variation at NORSAR and its effect on detectability. Bull. Seism. Soc. Am., 67, 479-492.

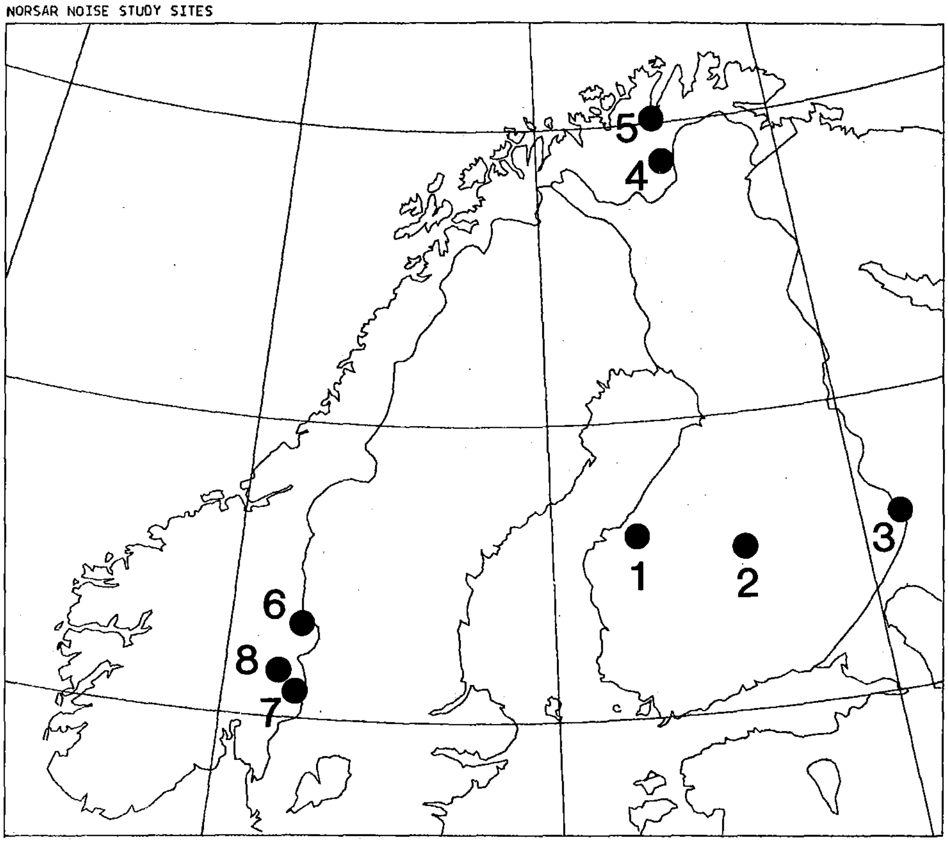

Fig. VI.7.1 Sites for the Fennoscandian noise survey 1981/82.

LOCATION NO	NAME	LAT. (°N)	LONG. (°E)	1981 DAY	HOUR	POWER DENSITY (DB REL TO 1 NM**2) .25	.50	1.0	2.0	4.0	8.0	16.
1	HOOPAKKA	63.05	22.71	250	1733	54	33	12	-13	-25	-38	-53
					2000	53	33	10	-15	-28	-40	-52
2	SUMIAINEN	62.72	26.15	251	1648	52	28	7	-15	-28	-40	-47
					2304	48	28	2	-16	-31	-42	-53
3	ILOMANTSI	62.92	31.31	254	1701	47	23	-2	-18	-28	-40	-52
				255	0932	45	20	-1	-21	-29	-40	-52
4	KARASJOK	69.35	25.17	223	1815	53	31	5	-12	-26	-39	-48
					2014	54	31	6	-13	-27	-40	-50
5	LAKSELV	70.03	25.00	224	1324	55	29	6	-12	-21	-32	-45
					1329	55	30	7	-12	-25	-36	-43
6	ENGEREN	61.55	12.19	232	2000	48	25	-1	-17	-33	-43	-53
					2202	48	27	2	-15	-30	-42	-53
7	KIRKENAER	60.41	12.14	301	1403	53	33	8	-9	-20	-32	-46
				1982								
8	NORESS	60.74	11.54	80	1000	39	27	4	-17	-28		
				84	1510	50	30	8	-13	-27		
				123	1350	52	30	3	-17	-30		
				130	1355	37	23	2	-16	-27		
				189	2105	42	26	0	-17	-28		

Table VI.7.1 Name and location for the 8 noise survey sites shown in Fig. VI.7.1. The power spectral level for each of the sites are given for 7 frequencies, each separated by one decade.

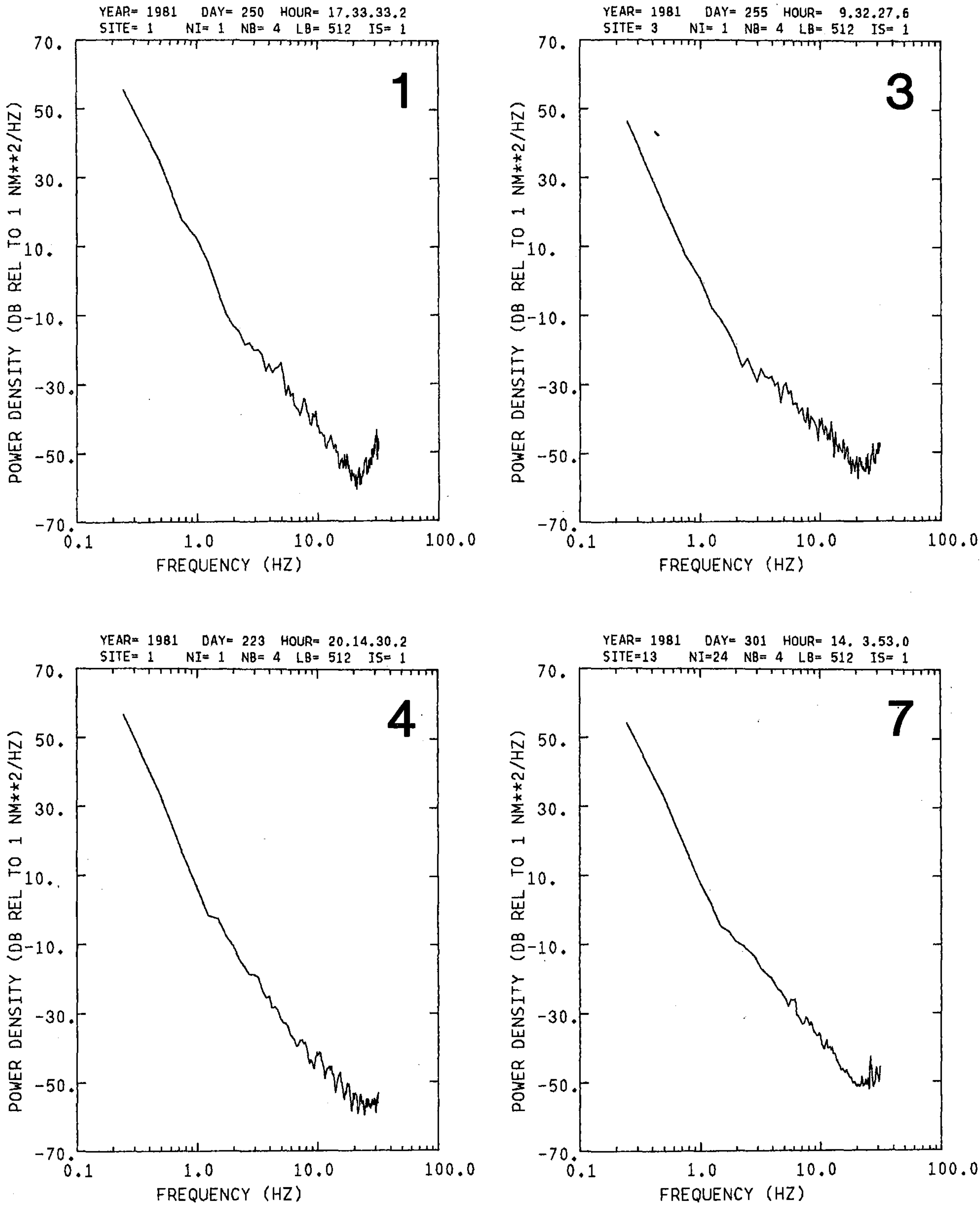

Fig. VI.7.2 Noise spectra from locations no. 1, 3, 4 and 7. The first 3 are from single seismometers, while no. 7 is averaged over 12 sites within 600 m of each other. Each spectrum is averaged over 4 blocks of data, each 512 samples long, and the sampling frequency is 62.5 Hz with an anti-aliasing filter at 25 Hz.

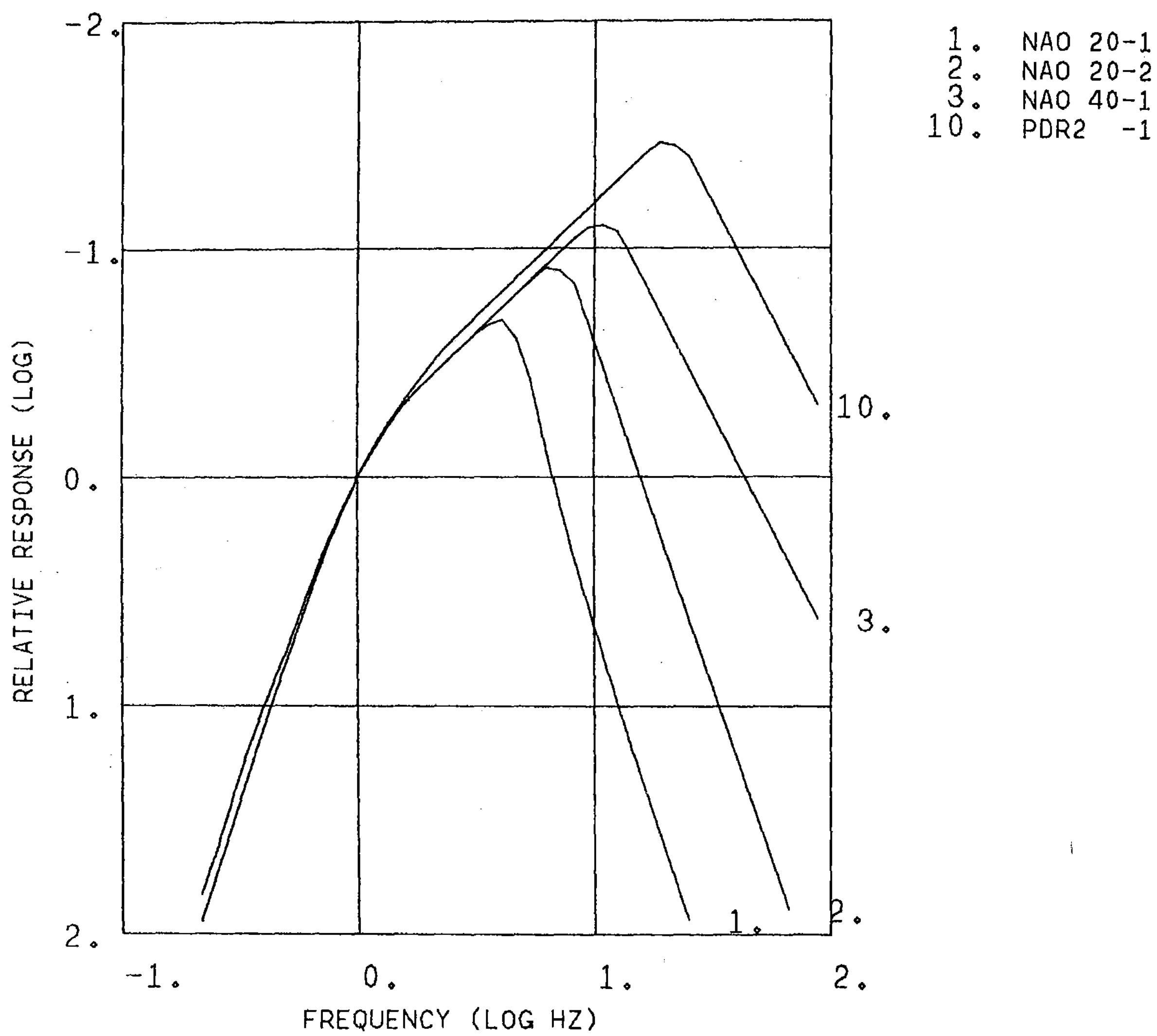

Fig. VI.7.3 Relative response functions for

1. NORSAR, 20 Hz sampling, 5 Hz filter
2. NORSAR, 20 Hz sampling, 8 Hz filter
3. NORSAR, 40 Hz sampling, 12.5 Hz filter
4. PDR-2, 62.5 Hz sampling, 25 Hz filter

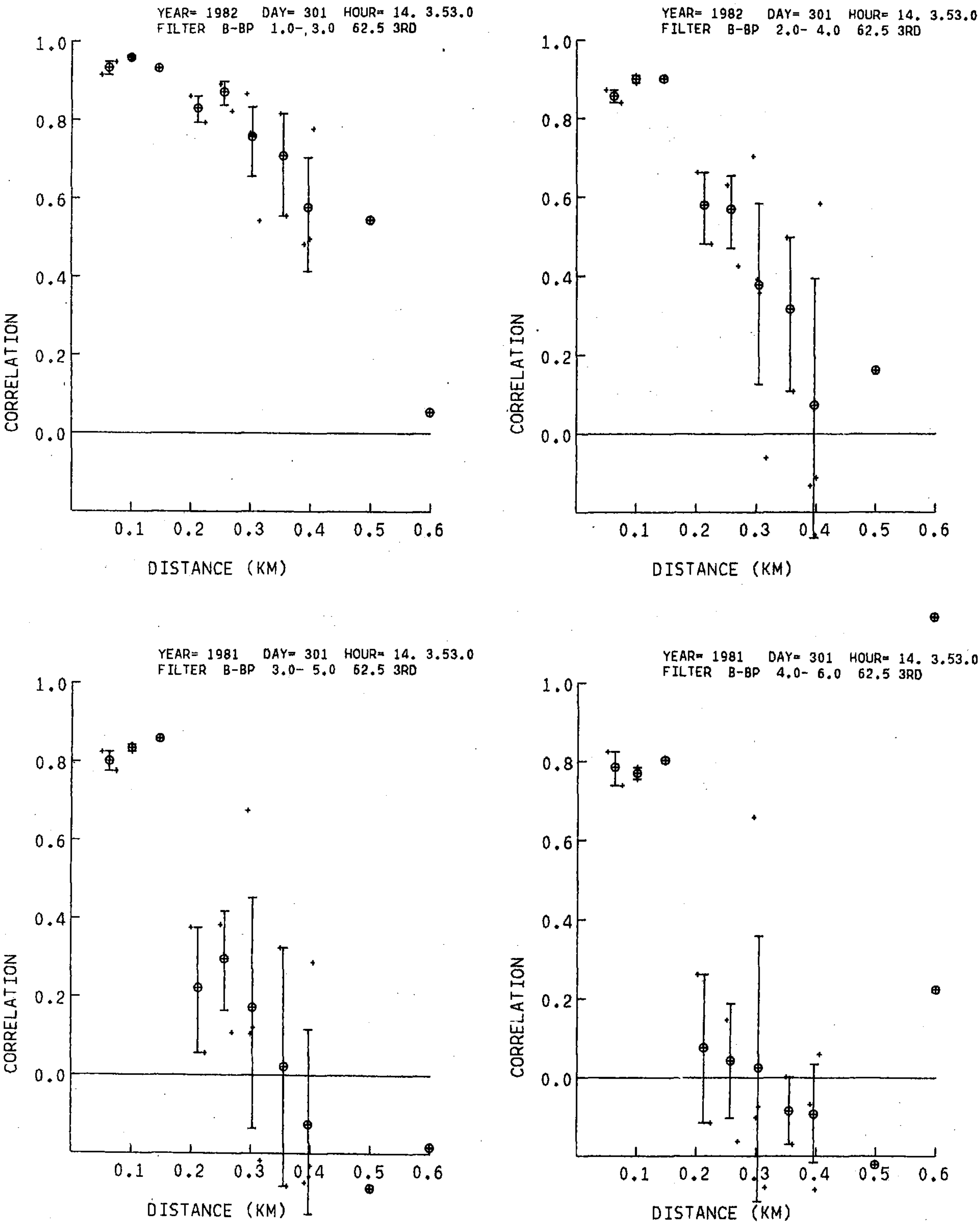

Fig. VI.7.4 Noise correlation vs. distance for location no. 7 (see Table VI.7.1), where 3 seismometers were successively moved around to cover inter-station distances between 50 and 600 m. The four graphs cover the frequency bands 1-3, 2-4, 3-5 and 4-6 Hz, respectively.

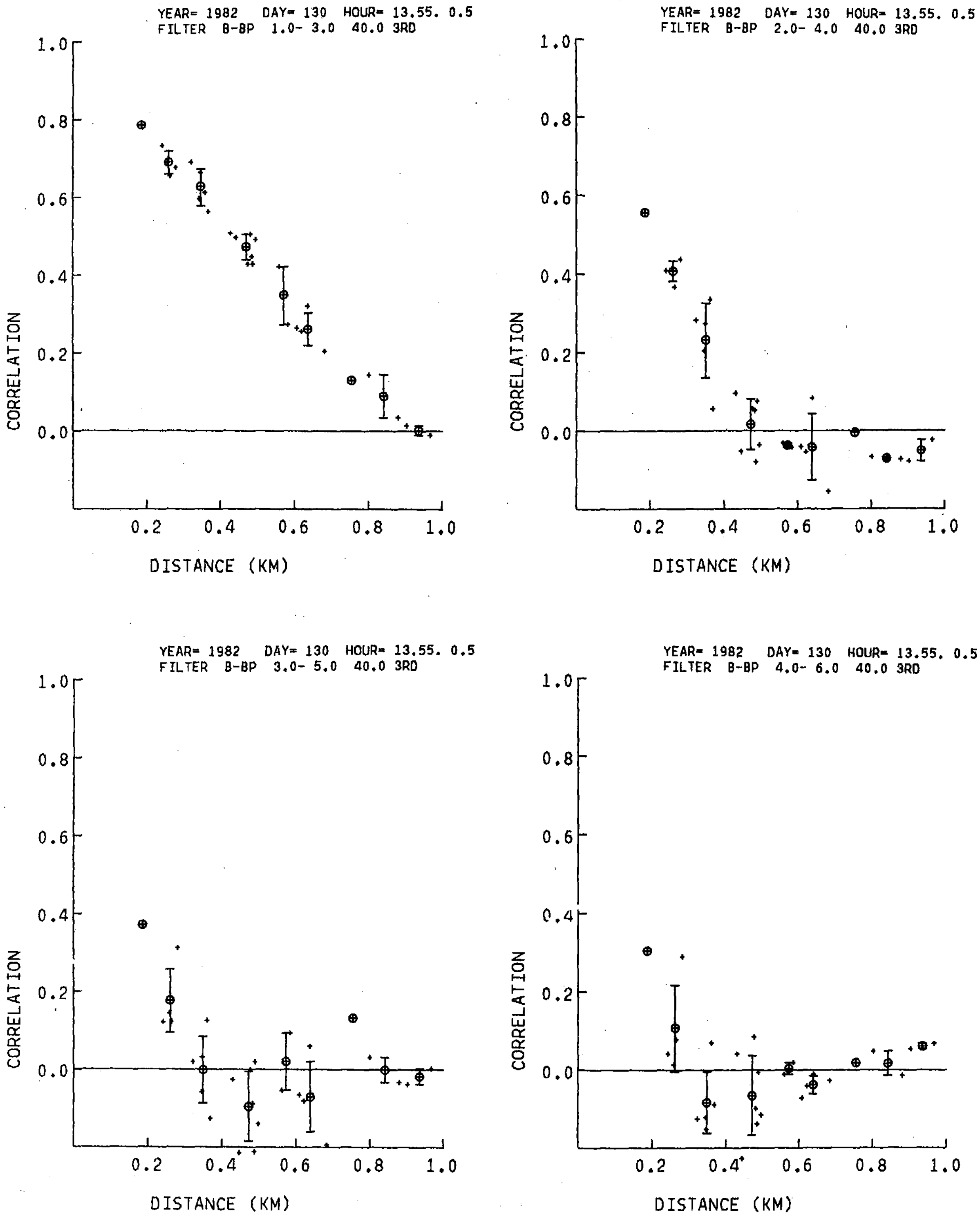

Fig. VI.7.6 Same as for Fig. VI.7.5, but for day 130/1982.

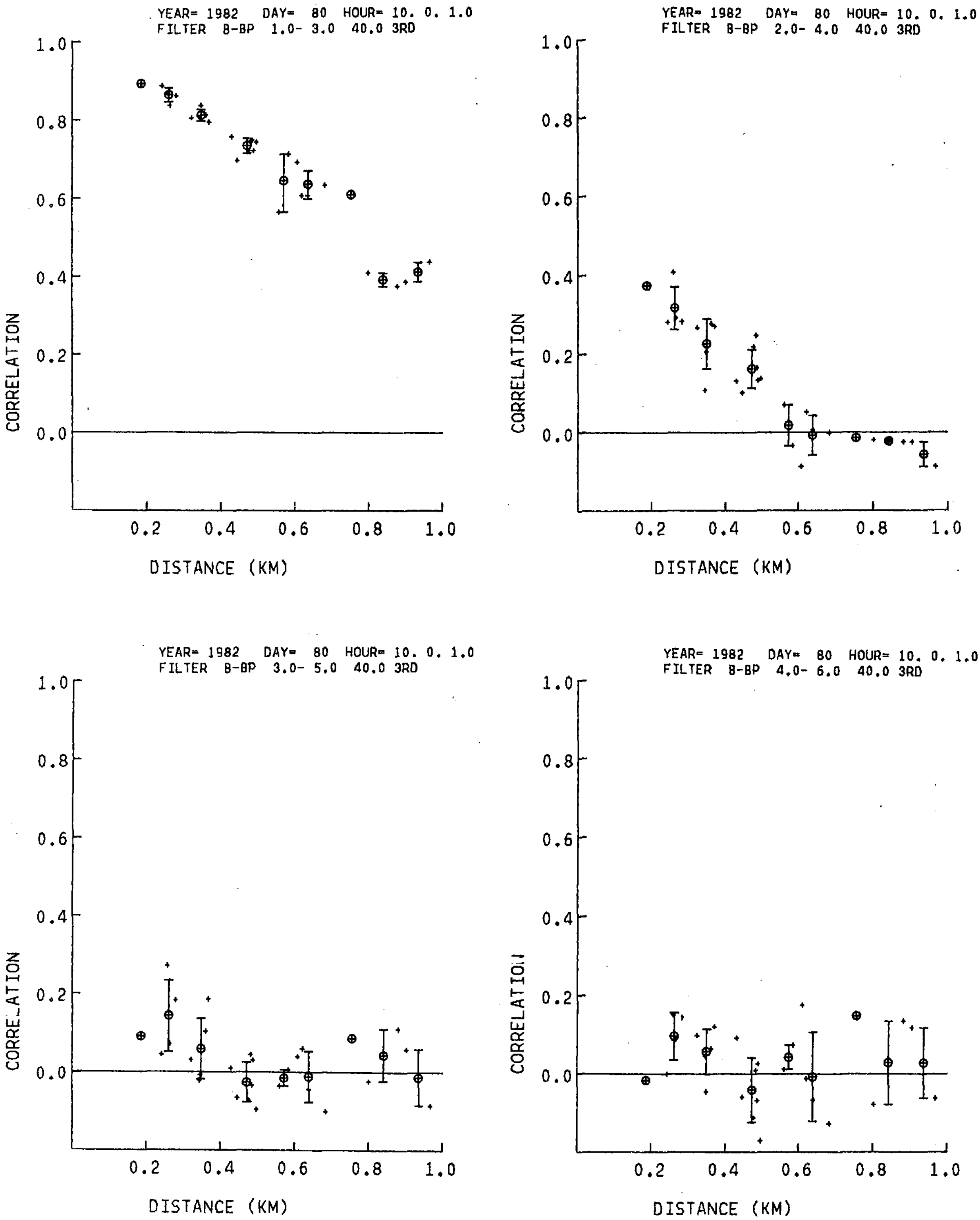

Fig. VI.7.5 Noise correlation vs. distance for location no. 8 (NORESS) and day 80/1982 (see Table VI.7.1). Eight channels sampled at 40 Hz have been used, and the frequency bands for the four graphs are the same as for Fig. VI.7.4.