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VII.4 Initial results from analysis of data recorded at the new regional array in Finnmark, Norway

During the summer and fall of 1987, a regional array was installed near the town of Karasjok in the county of Finnmark in northern Norway. The new Finnmark array was designed to be as closely as possible a copy of the NORESS regional array, which was established in southern Norway in 1984. The geometries of the two arrays are therefore practically identical (deviations between corresponding sensor positions are of the order of a few tens of meters, due to local terrain conditions), and the data outputs are the same for the two arrays. Fig. VII.4.1 shows the location of the two regional arrays in Norway, and also the location of the FINESA regional array in Finland, which was described by Korhonen et al (1987). The geometry of NORESS (and for most practical purposes, also the geometry of the Finnmark array) is shown in Fig. VII.4.2.

Data from the new Finnmark array have been transmitted continuously via satellite to the NORSAR data processing center at Kjeller since November 1, 1987. The data are subjected to automatic detection processing, with a beam deployment identical to the one used for NORESS.

In the following, we report on some findings resulting from analysis of data from the new Finnmark array. It should be emphasized at the outset that the available data cover no more than a two-week period, and that a comprehensive assessment of the capabilities of the new array must await the collection of data covering a longer time span.

Noise spectra

Fig. VII.4.3a shows corrected noise spectra for altogether 17 elements of the new Finnmark array (the vertical sensors at A0 and the C- and

D-rings, see Fig. VII.4.2), taken at 00.00 GMT on day 315. For comparison, NORESS noise spectra for the same number of channels and taken at the same time, are shown in Fig. VII.4.3b. From these figures, it is seen that below 2.0 Hz, the Finnmark array experiences a higher noise level than NORESS, whereas above 2.0 Hz the Finnmark site is clearly the quieter.

The high noise level at low frequencies at the Finnmark site has been confirmed by other data and is typically even higher than shown in Fig. VII.4.3a. At the time of these spectra, the nearby coast of Finnmark experienced a wind force 4, which is moderate. The noise level at these low frequencies is generally believed to be governed by the passage of major weather fronts over the open ocean. Therefore, it should not be unexpected to find the higher microseismic noise levels at the Finnmark array, since this array is located closer to the coast than the NORESS array.

For the frequency range above 2 Hz, the noise level at the Finnmark site appears to be 3-5 dB below that of NORESS. A possible explanation here is that the noise in this band is lower at the northern site because of a lower population density and also lower level of traffic and industrial activities, compared to the NORESS site. These noise levels must also be rated as low relative to year-round averages for NORESS, as investigated by Fyen (1987).

Figs. VII.4.4a and 4b each show ten uncorrected spectra, taken hourly between 00.00 GMT and 10.00 GMT of day 315, for the Finnmark and NORESS arrays, respectively. Each single spectrum represents an average of 17 spectra for the vertical sensors of A0, the C- and D-rings. The NORESS spectra show the well-established (Fyen, 1986a,b; 1987) difference between night-time and day-time noise characteristics (particularly around 6 Hz). The Finnmark data are generally below those of the NORESS site for frequencies above 2 Hz. The two or three curves with the higher noise power in Fig. VII.4.4a represent cases of high frequency noise bursts at the Finnmark site during daytime. These bursts are visually confirmed by careful inspection of the seismograms. A more comprehensive study is needed to clarify the origin of this noise. There is so far, however, no indication of constant noise sources like power plants and sawmills.

It should be emphasized again that in order to establish reliable estimates of ambient noise levels at the new array site, studies like those undertaken by Fyen (1986a,b; 1987) for NORESS are needed. The material analyzed so far, however, indicates that in the range of primary interest to regional seismic verification (i.e., above 2 Hz), the noise level at the new Finnmark array site is generally somewhat lower than the NORESS noise level.

Noise suppression by beamforming

The NORESS array has proved very proficient in the enhancement by beamforming of the SNR, yielding gains that are often of the order of or even in excess of $\sqrt{N}$ (N being the number of sensors used in the beamforming). It has been shown that this success is largely due to the highly effective noise suppression that can be obtained by selecting appropriate sub-geometries for the various signal frequencies. As a first check on the new array's capabilities in this regard, noise suppression curves were computed and compared with corresponding results from NORESS.

In Fig. VII.4.5a, the noise suppression in the frequency range 0-20 Hz for vertical beamforming (no shifts introduced) is shown for three one-minute intervals taken hourly at 00.00, 01.00 and 02.00 GMT on day 315. The sub-geometry used is that of A0, the B- and C-ring instruments (13 sensors). The dots in this figure represent average values for NORESS that are taken from Fyen (1986c). The √N level is at about -11 dB, and the general impression left from this figure is that the new array is as effective in suppressing noise as NORESS, for this sub-geometry. For another sub-geometry, comprising the sensors of A0, the C- and D-rings, corresponding results are given in Fig. VII.4.5b. Again, we see that the noise suppression capability is comparable to or maybe even better than the average performance of NORESS. This strongly suggests that the spatial characteristics (e.g., correlation lengths vs. frequency) of the noise field are very similar to those found at NORESS. It has previously been established (Korhonen et al, 1987) that the NORESS and FINESA arrays exhibit strong similarities in this regard.

Analysis of data from two regional events located at the Finnmark array

As examples of regional events recorded on the Finnmark array, we present the records for two presumed mining explosions in the Kola peninsula of the USSR.

The C-ring seismograms for the first event are shown in Fig. VII.4.6. The event occurred at 67.6°N, 34.0°E (according to the University of Helsinki bulletin), at an epicentral distance of 408 km and an azimuth of 117.9°. The phases Pn, Pg, Sn and Lg can be clearly identified by visual inspection. These phases were subjected to wide-band slowness analysis, with results given in Figs. VII.4.7 and VII.4.8. We see that the phase velocities derived are in the expected range for these phases and that deviations from the "true" azimuth are within 6-7°.

Data for the second event are shown in Fig. VII.4.9. This event is located at 68.1°N, 33.2°E, at an epicentral distance of 349 km and an azimuth of 113.7°. Besides the phases identified for the first event, we now also see a clearly developed Rg phase. It is of particular interest to note the difference between the two events in this regard, particularly since they are separated by not more than about 60 km. The occurrence of Rg waves in the records for events of epicentral distances of the order of 350 km also sharply contrasts what we have found at NORESS, where Rg waves are never observed beyond 100 km distance. The results of the wide-band slowness analysis of the phases Pn, Pg, Lg and Rg for this event are shown in Figs. VII.4.10 and VII.4.11. Again we see that the phase velocities are reasonable, and the azimuths deviate by not more than 5° from the "true" value.

Regional event detection

An initial study has been made comparing the regional event detection performance of the two arrays in Norway. A two-week period (Oct 31 - Nov 18, 1987) was selected for this purpose, and analysis of RONAPP processing results for the two arrays was conducted. For both arrays, the beam deployments and thresholds were identical, and the same as those used for the past two years in regular NORESS operation.

Fig. VII.4.12 shows a map displaying all regional events located by NORESS during this time period, whereas Fig. VII.4.13 gives a similar map for the Finnmark array. We recall that in order for one array to locate a regional event, at least two phases (P and Lg) from that array must be detected and associated.

Comparing these two figures is quite instructive, and probably gives a reliable impression of what can be expected during long-term operation. The actual number of located events is similar for the two arrays (NORESS 152, Finnmark 117). However, there is almost no overlap of the two populations; in fact only 8 events were located by both arrays. The large majority of located events are within 500 km of the respective arrays, and represent in most cases presumed local explosions of low magnitude ($M_L < 1.5$). Sites where such explosions are clustered can be easily identified on the plots. It is noteworthy in particular that the Finnmark array detects and locates a large number of mining explosions in the Kola peninsula.

Fig. VII.4.14 shows a map of all events of estimated $M_L \geq 2.0$ located by at least one array. In those cases when both arrays located the same event, the location by the closest array was chosen. Events with at least one confirming phase (P or Lg) from the other array are encircled. Details pertaining to the figure are given in Table VII.4.1.

Compared to the previous figures, it is clear that relaxing the criterion for "common" events to requiring only one confirming phase from the other array significantly increases the overlap of the populations. The majority of events in Fig. VII.4.14 are thus detected by both arrays. It is particularly interesting to observe the good performance for the event cluster near 65°N 40°E, which is at a considerable distance from both arrays (700 and 1500 km, respectively). These events were in the magnitude range 2.5-2.7 and the locations have been independently confirmed by the Finnish network.

In almost all cases of confirming detections by one phase only, this corresponded to a P phase (Table VII.4.1). This result is somewhat surprising in view of earlier P and Lg detection studies for NORESS and may not be representative. Further assessment of the joint detection and location potential of the two arrays will require a more extensive data base, and will be the subject of further study.

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Fyen, J. (1986a): NORESS noise spectral studies, preliminary report. Semiannual Technical Summary, 1 Oct 1985 - 31 Mar 1986, NORSAR Sci. Rep. No. 2-85/86, Kjeller, Norway.

Fyen, J. (1986b): NORESS noise spectral studies - noise level characteristics. Semiannual Technical Summary, 1 Apr 1986 - 30 Sept 1986, NORSAR Sci. Rep. No. 1-86/87, Kjeller, Norway.

Fyen, J. (1986c): NORESS noise spectral studies - beam suppression. Semiannual Technical Summary, 1 Apr 1986 - 30 Sept 1986, NORSAR Sci. Rep. No. 1-86/87, Kjeller, Norway.

Fyen, J. (1987): NORESS noise spectral studies. Noise level characteristics. Semiannual Technical Summary, 1 Oct 1986 - 31 Mar 1987, NORSAR Sci. Rep. No. 2-86/87, Kjeller, Norway.

Korhonen, H., S. Pirhonen, F. Ringdal, S. Mykkeltveit, T. Kværna, P.W. Larsen and R. Paulsen (1987): The Finesa array and preliminary results of data analysis. Univ. of Helsinki, Inst. of Seismology, Report S-16.

Reference Array		NORESS	Finnmark
Total no. of events located by reference array		152	117
No. of events $M_L \geq 2.0$		31	42
No. of events $M_L \geq 2.0$ located by the reference array, detected or not detected by the other array.	Both P and Lg	8	8
	P only	14	12
	Lg only	1	1
	Not detected	8	21

Table VII.4.1 Statistics of detected and located regional events for the two arrays in Norway during a two-week test period.

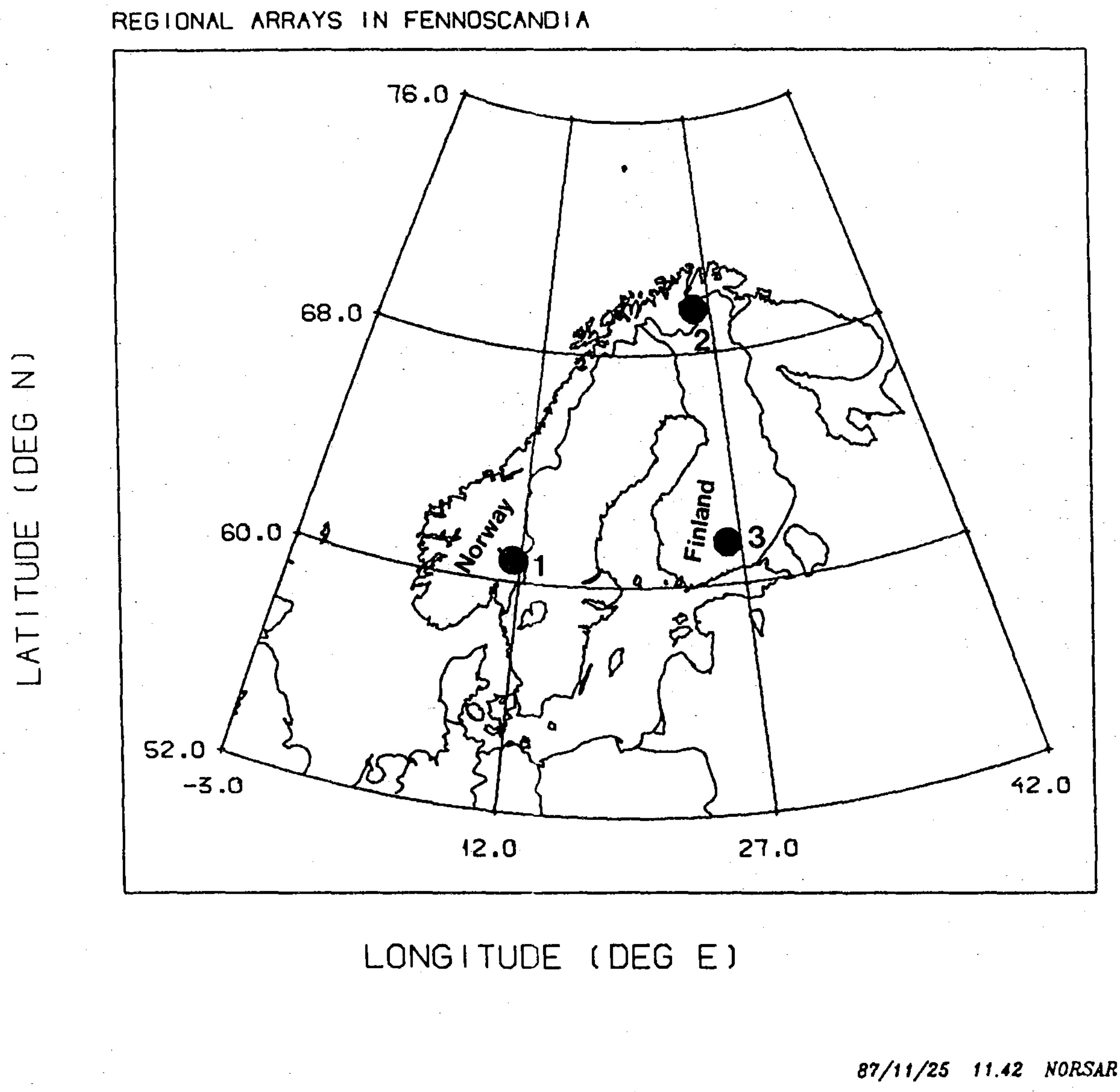


Fig. VII.4.1 The figure shows the network of three regional arrays in Fennoscandia. 1: The NORESS array in southern Norway; 2: The new array in Finnmark, northern Norway; and 3: The FINESA array in Finland.

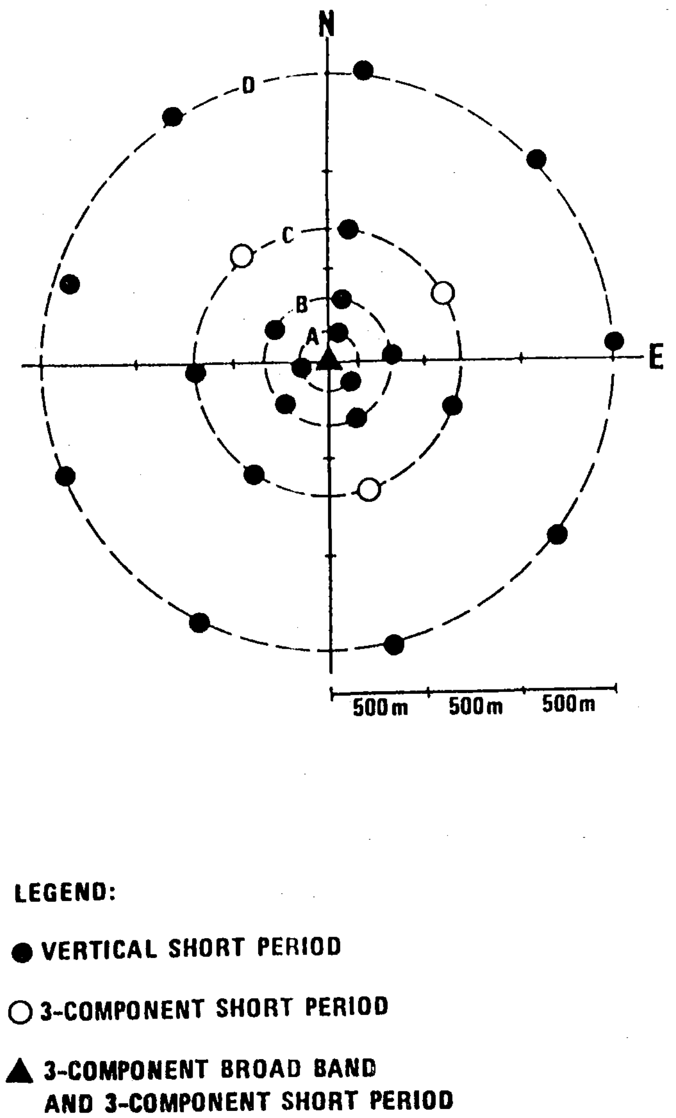


Fig. VII.4.2 The geometry of the NORESS array. The geometry of the new Finnmark array comes very close to being identical to that of NORESS; deviations between corresponding element positions are of the order of some tens of meters. The channel assignments (vertical only vs. three-component, short period vs. broadband) are identical for the two arrays. The short period instrument at the center of the array is denoted A0.

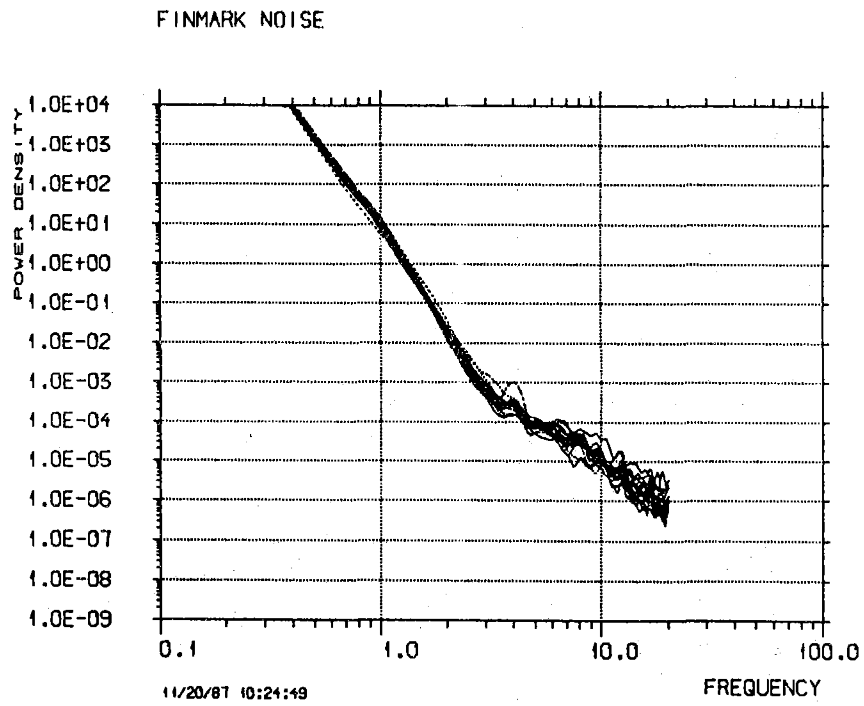


Fig. VII.4.3a Noise spectra corrected for system response for the Finnmark array for 17 vertical channels at A0, the C- and D-rings. The spectra are base don one minute of data at 00.00 GMT on day 315. The power density is in nm^2/Hz.

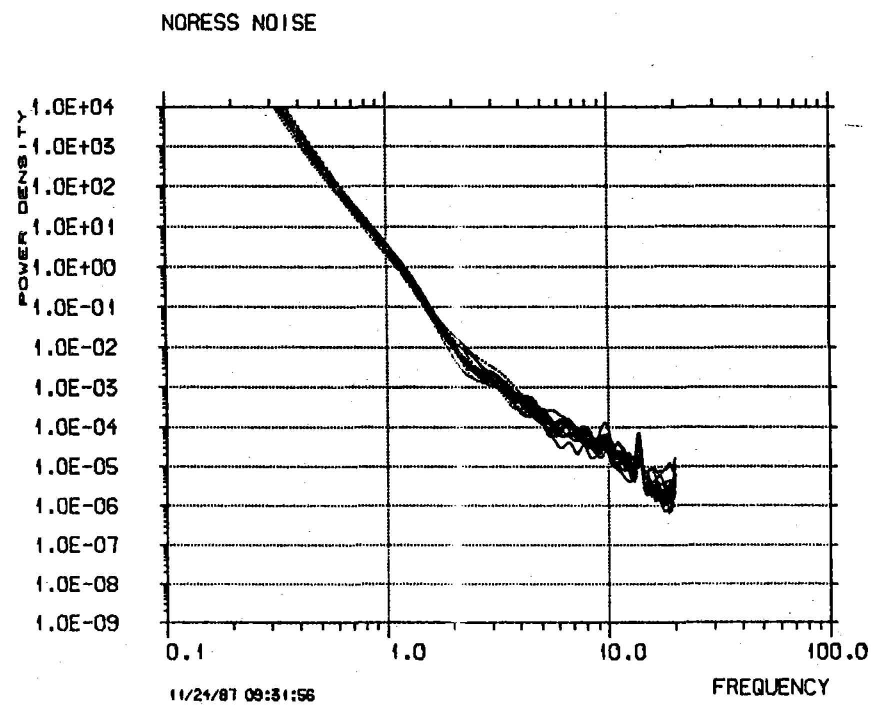


Fig. VII.4.3b Same as Fig. VII.4.3a, but for NORESS data taken at 00.15 GMT on day 315.

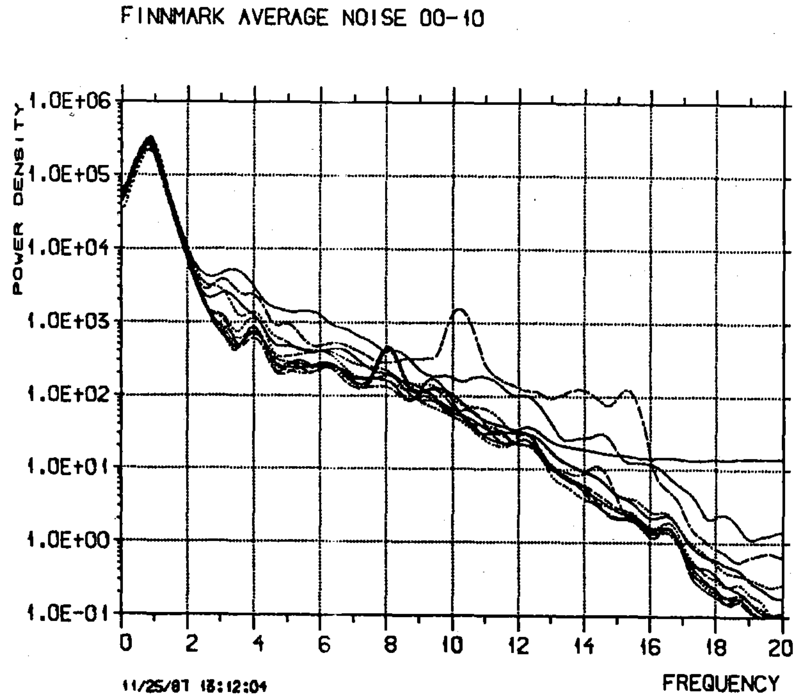


Fig. VII.4.4a Uncorrected noise spectra for the Finnmark array for ten one-minute intervals taken hourly between 00.00 and 10.00 GMT on day 315. Each spectrum represents an average of the 17 vertical sensors of A0, the C- and D-rings.

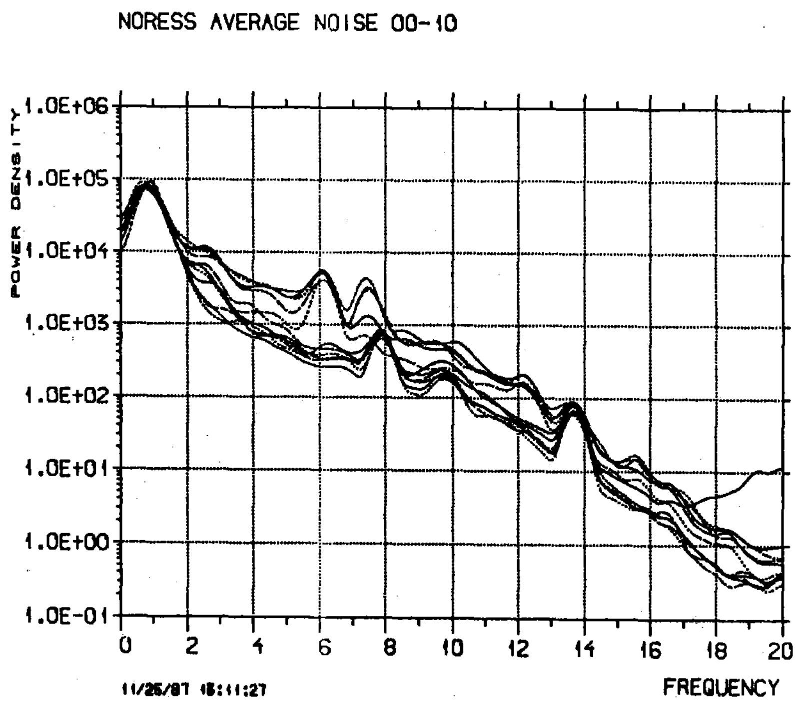


Fig. VII.4.4b Same as Fig. VII.4.4a, but for NORESS data taken hourly between 00.00 and 10.00 GMT on day 315.

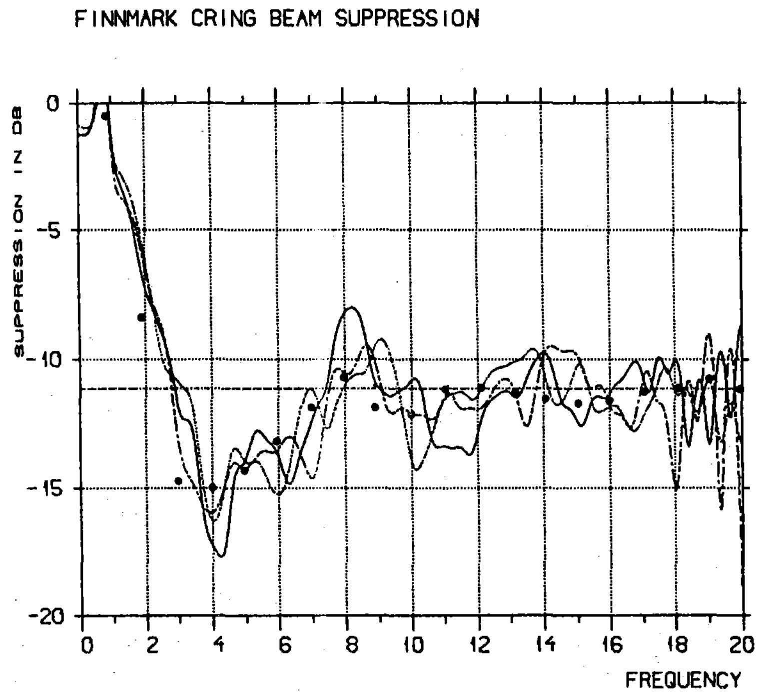


Fig. VII.4.5a Finnmark array noise suppression by beamforming for the sub-geometry comprising the AO, B- and C-ring sensors. To produce these curves, a vertical beam is formed and the spectrum for this beam is divided by the average of the single sensor spectra. The three curves result from one minute of data taken hourly at 00.00, 01.00 and 02.00 GMT on day 315. The dots represent typical NORESS noise suppression values for this sub-geometry. The horizontal line at -11.1 dB represents √N suppression for 13 sensors.

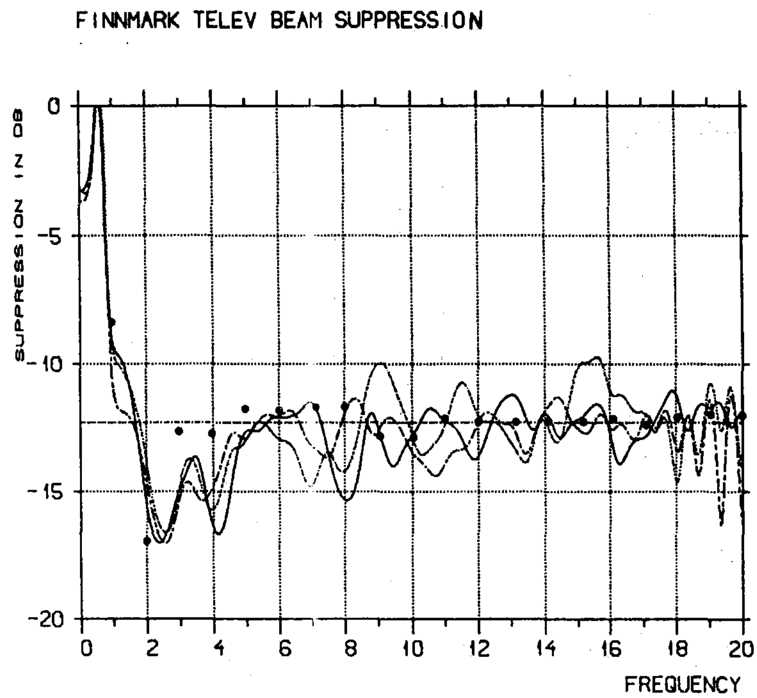


Fig. VII.4.5b Same as Fig. VII.4.5a, but for the sub-geometry comprising the sensors of AO, the C- and D-rings. The horizontal line at -12.3 dB represents √N suppression for 17 sensors.

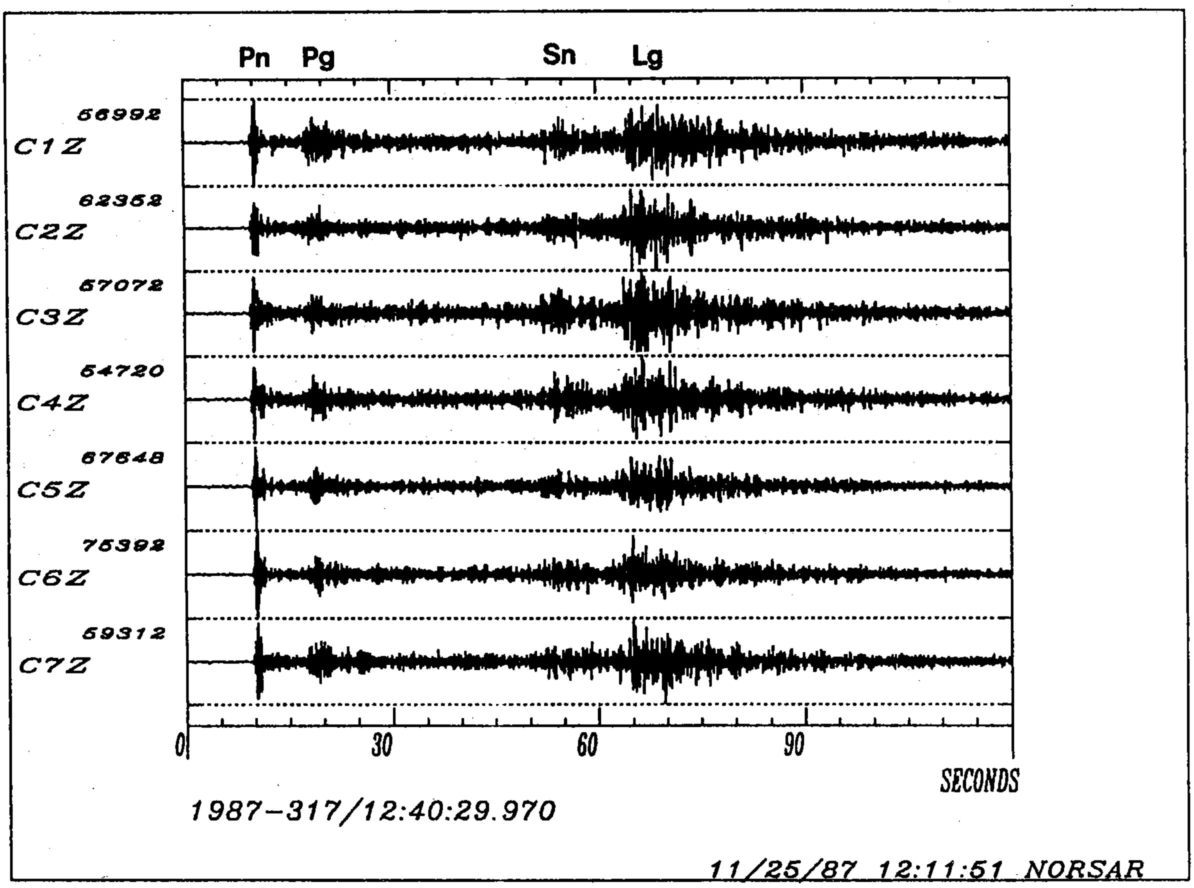
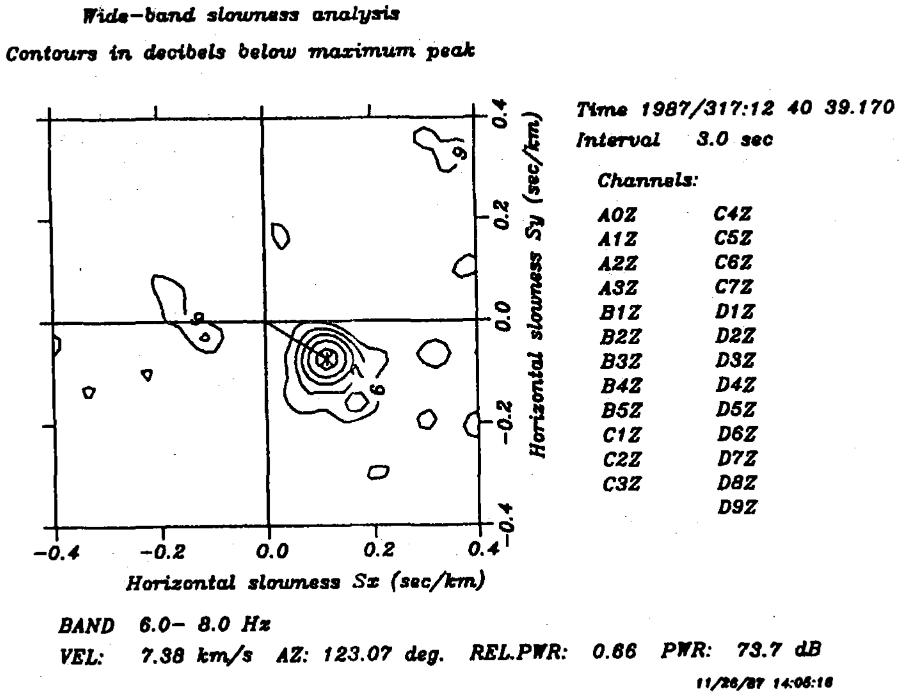


Fig. VII.4.6 Finnmark array data for a presumed mining explosion at 67.6°N, 34.0°E. The plot shows data for the vertical instruments of the C-ring.

Pn



Pg

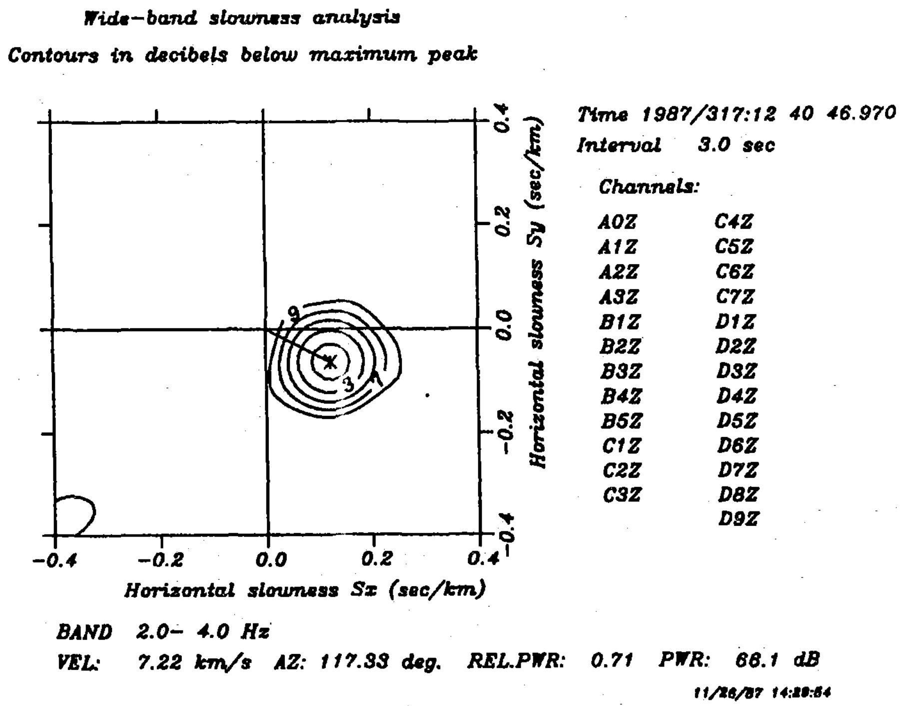
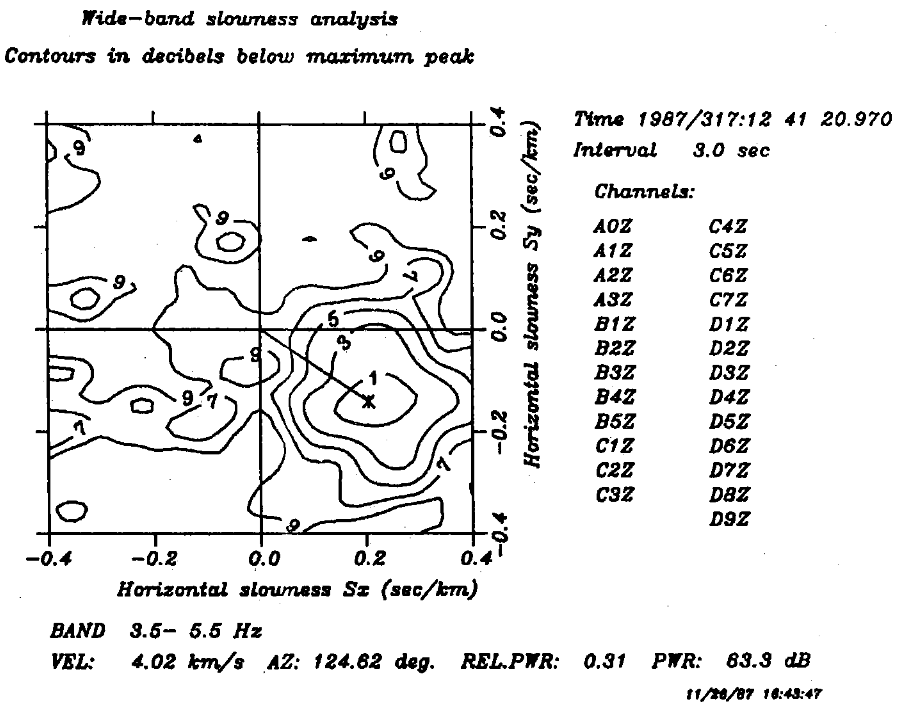


Fig. VII.4.7 Wide-band slowness spectra for the Pn phase (top) and Pg phase (bottom) for the event in Fig. VII.4.6.

Sn



Lg

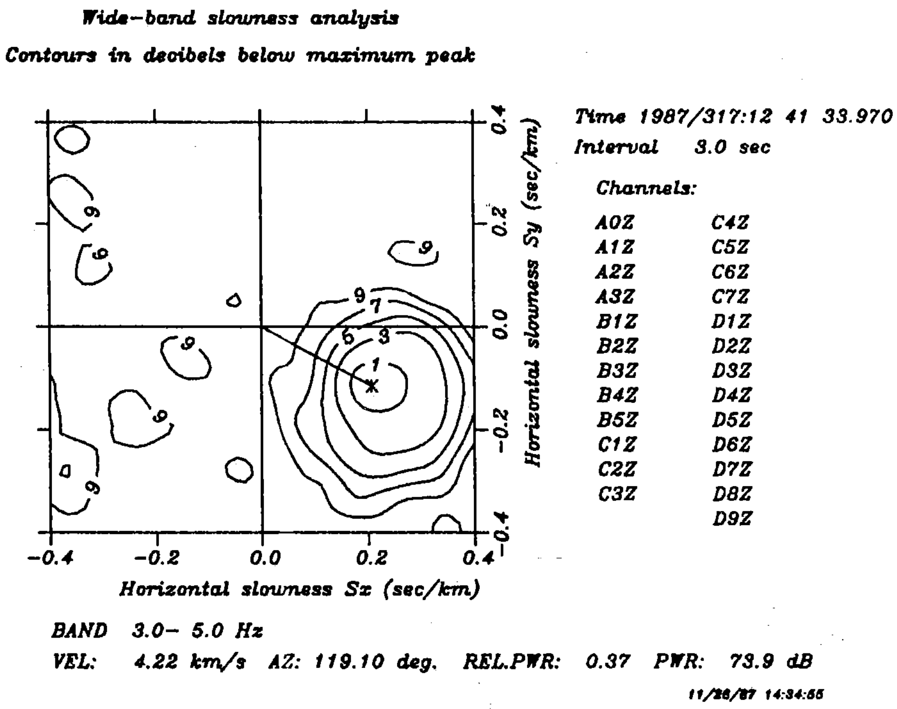


Fig. VII.4.8 Wide-band slowness spectra for the Sn phase (top) and Lg phase (bottom) for the event in Fig. VII.4.6.

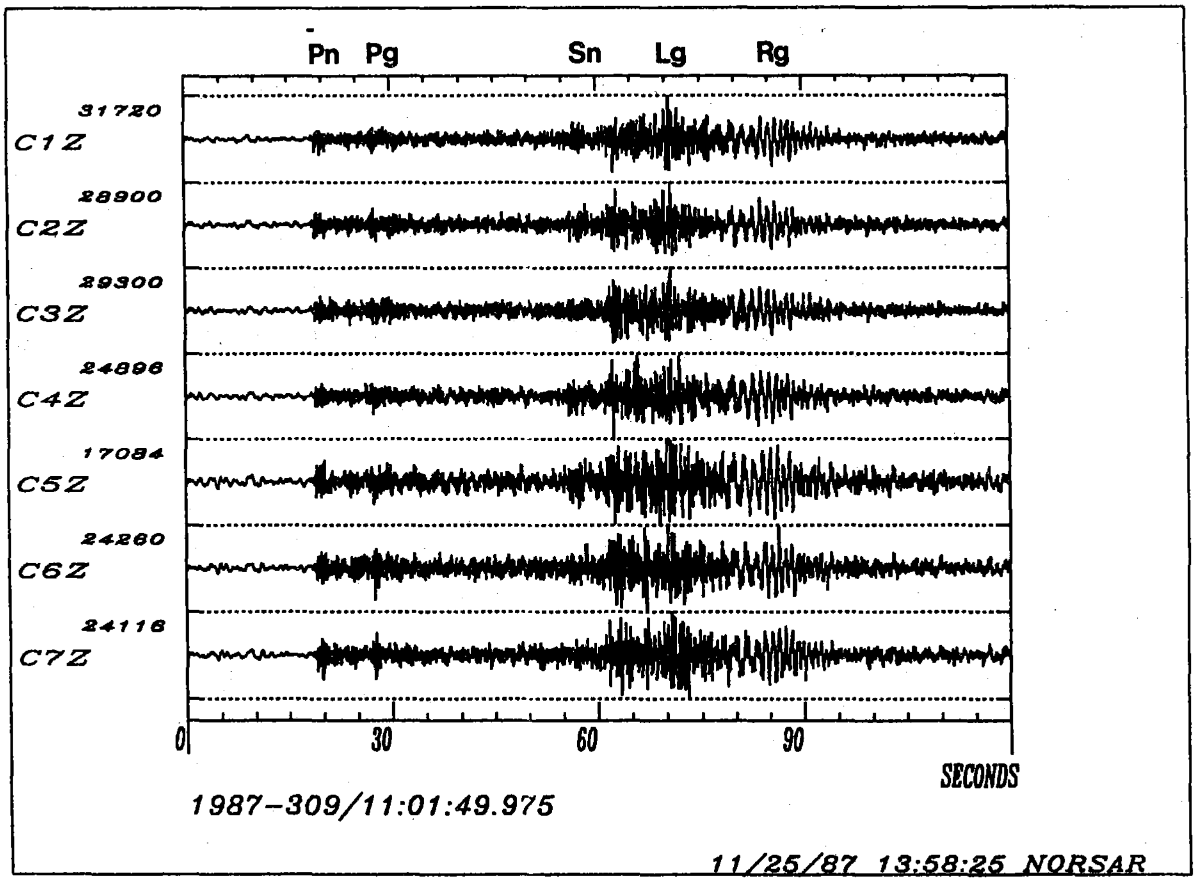
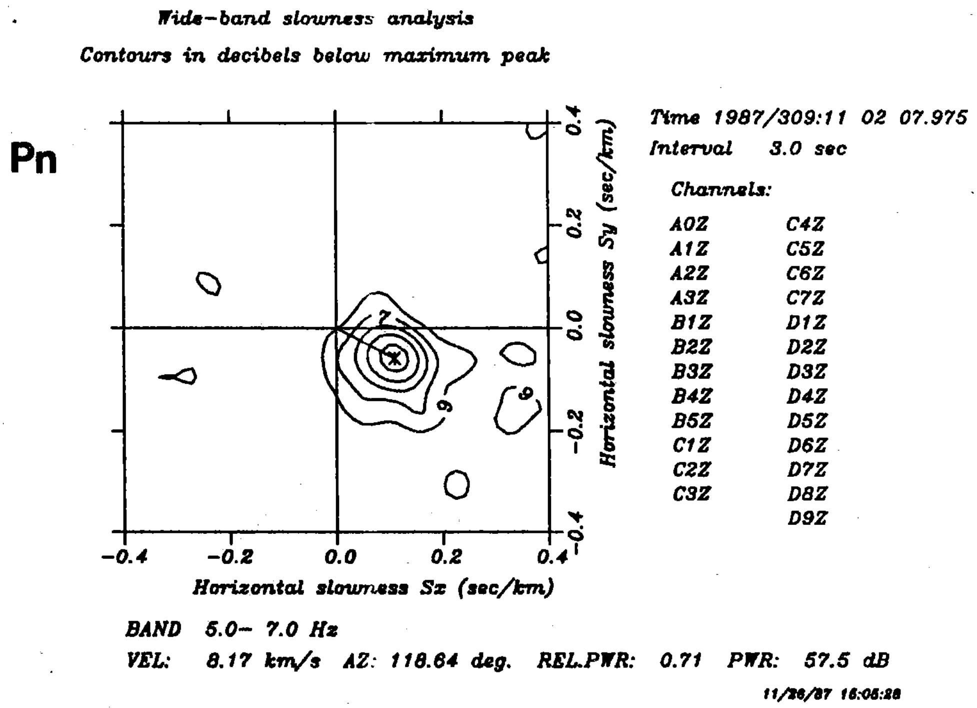


Fig. VII.4.9 Finnmark array data for a presumed mining explosion at 68.1°N, 33.2°E. The plot shows data for the vertical instruments of the C-ring.



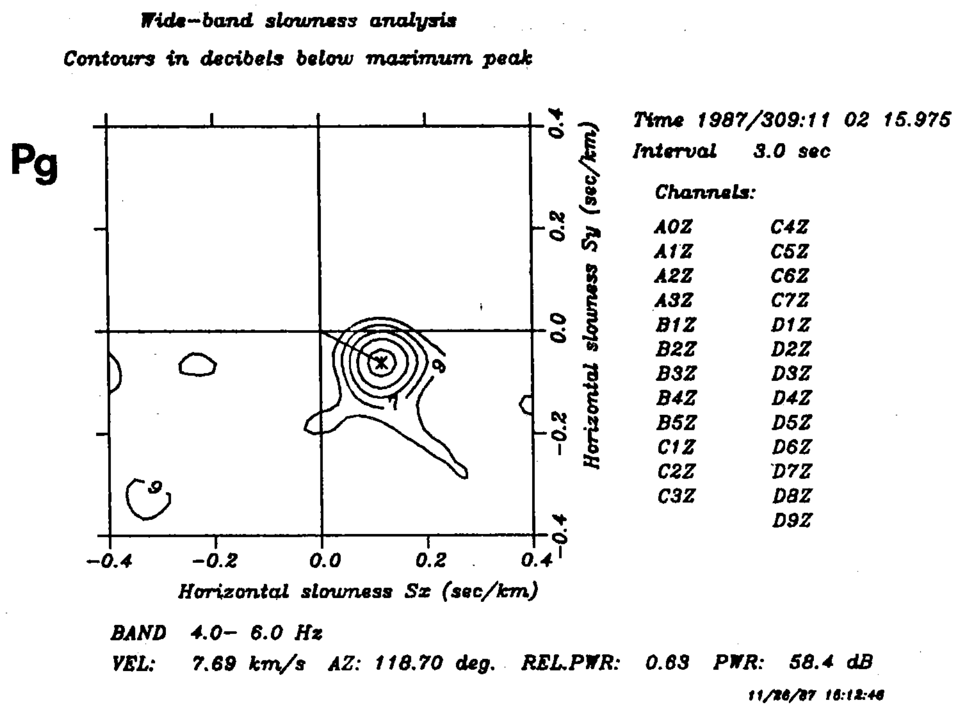
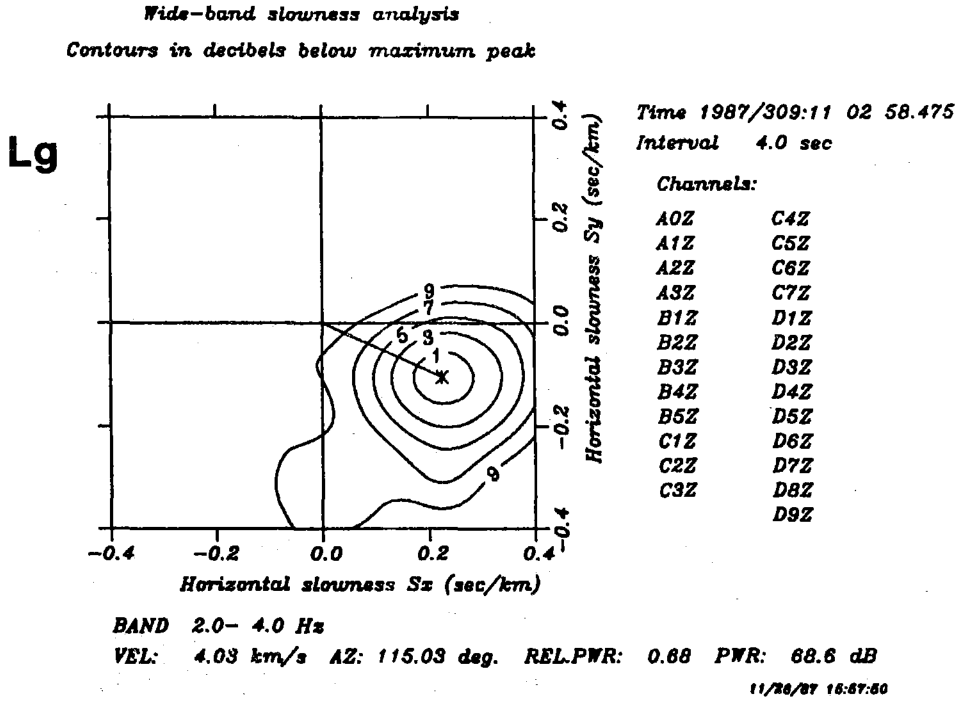


Fig. VII.4.10 Wide-band slowness spectra for the Pn phase (top) and Pg phase (bottom) for the event in Fig. VII.4.9.



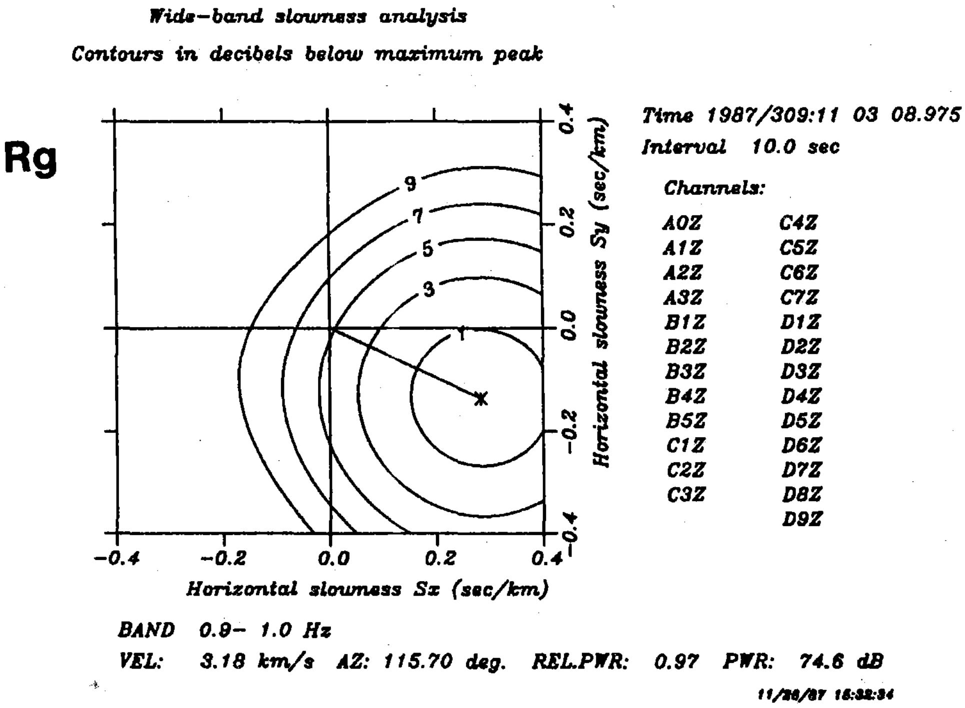


Fig. VII.4.11 Wide-band slowness spectra for the Lg phase (top) and Rg phase (bottom) for the event in Fig. VII.4.9.

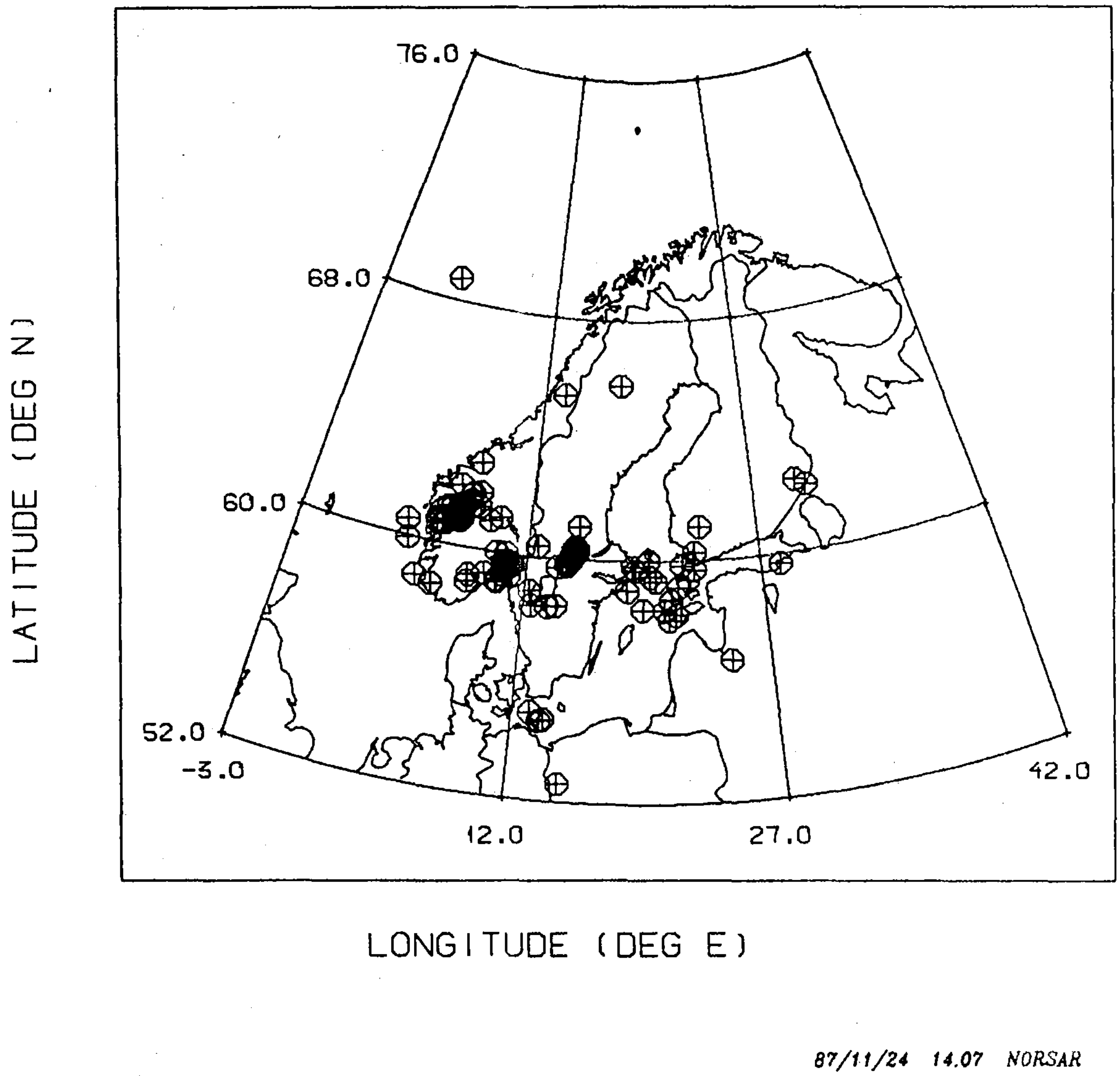


Fig. VII.4.12 Regional events located by the NORESS array during a two-week test period.

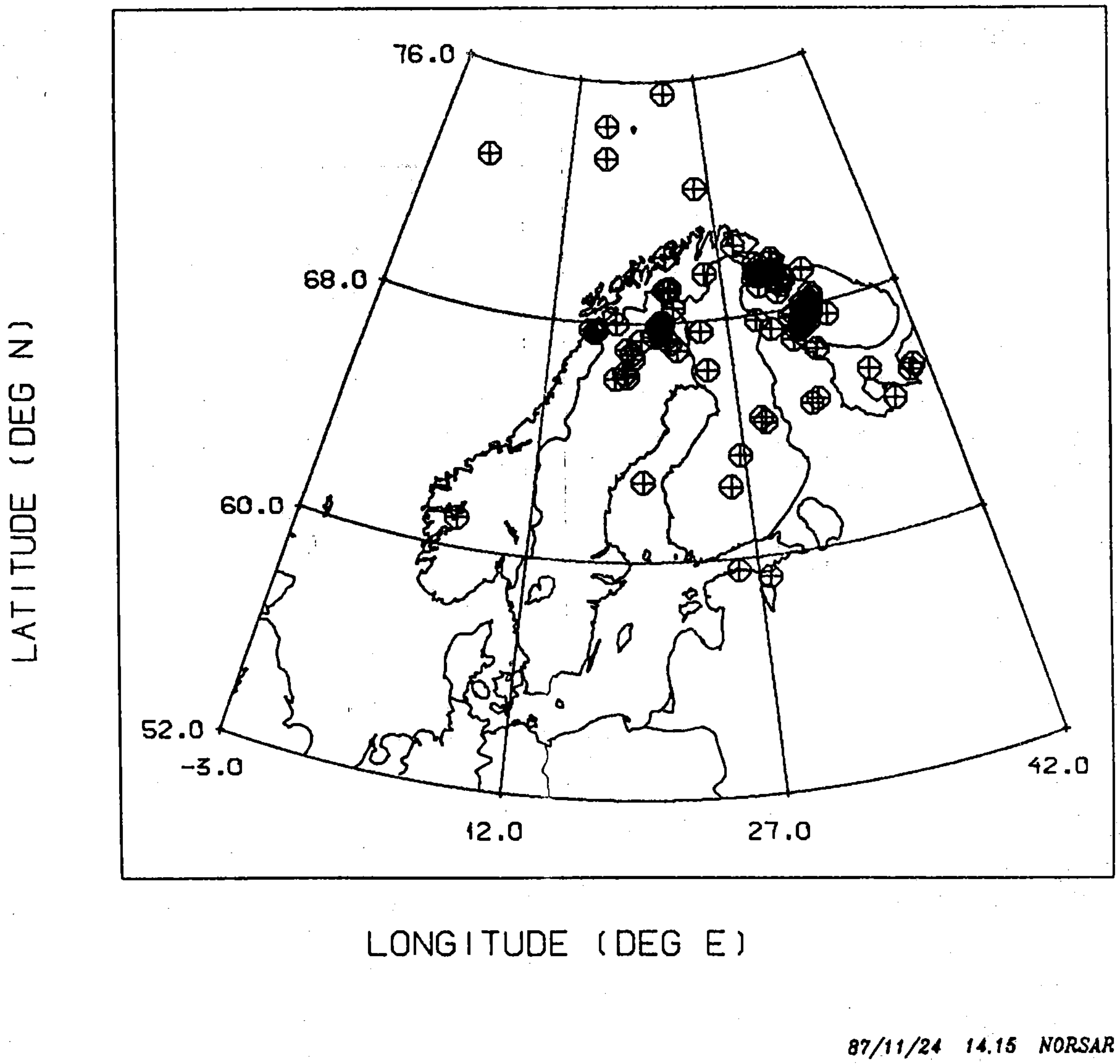


Fig. VII.4.13 Regional events located by the Finnmark array during a two-week test period.

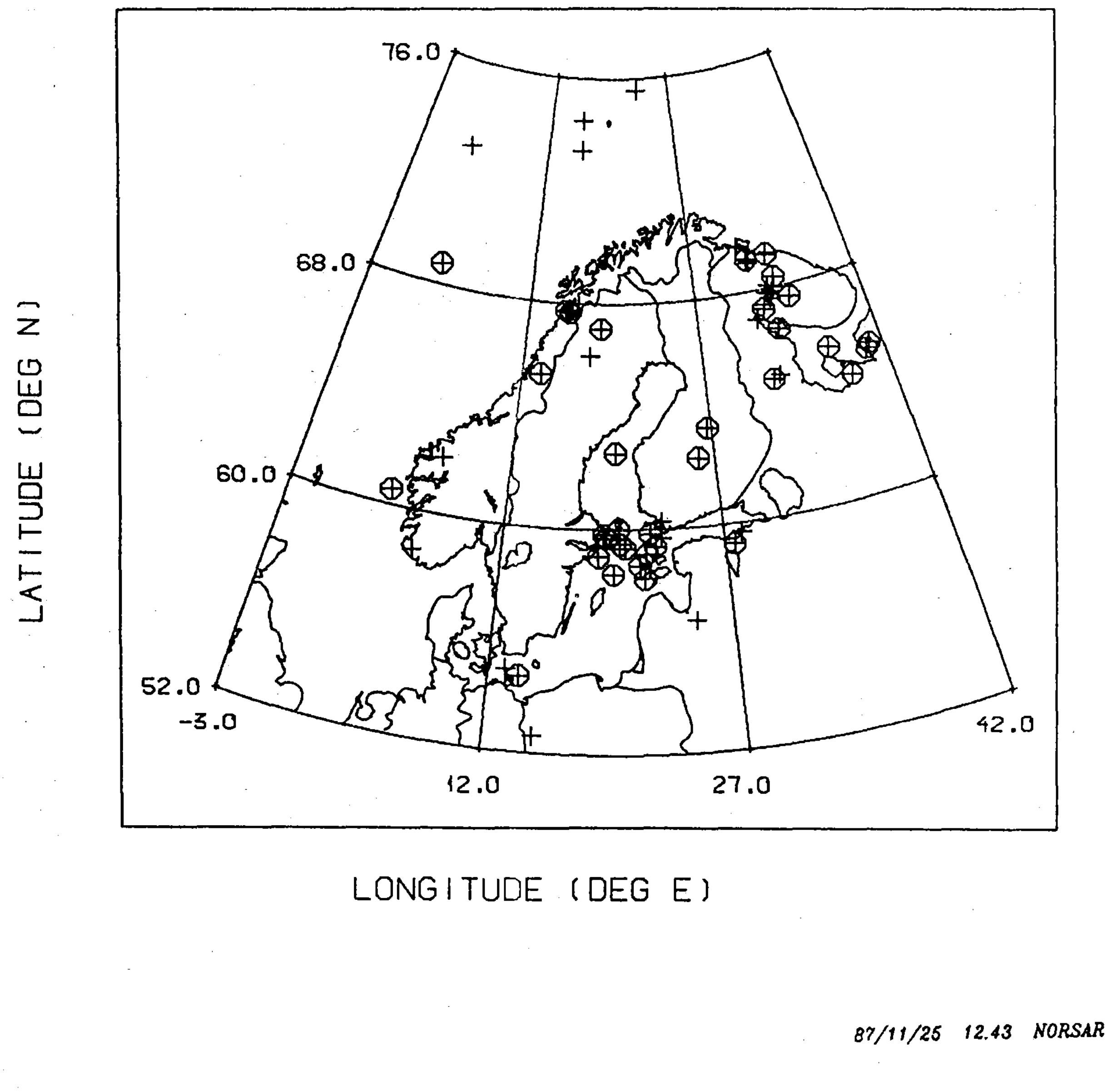


Fig. VII.4.14 Regional events of $M_L > 2.0$ located by at least one of the two arrays in Norway during a two-week test period. Events with at least one confirming phase from the other array are encircled.