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VII.2 Sources of short-term fluctuations in the seismic noise level at NORESS

The small-aperture array NORESS in southern Norway provides a unique tool to investigate the spatial coherence and directionality of the ambient seismic noise field. By using techniques such as narrow-band and wide-band frequency-wavenumber analysis, both apparent velocity and azimuth of the noise as well as signals can be reliably determined. Three years of operation of an automatic short-term to long-term (STA/LTA) detector algorithm has further offered the possibility of an extensive study of the short-term variability of the seismic noise field (i.e., noise bursts of a few seconds length). In conjunction with the associated automatic determination of apparent velocity and azimuth, this detector system provides a unique data base for detailed characterization of propagating noise phases.

An abrupt increase in the seismic noise level will cause an STA/LTA detector algorithm to delare a detection. The three-year period of continuous processing of data from from NORESS, has shown that this kind of detections sometimes completely dominates the output report from the real-time processor. In most cases these noise bursts can be separated from the local and regional S-phases on the basis of their relatively low apparent velocity estimates. But there is clearly a need to understand the mechanisms causing these phenomena and their implications on real-time array processing. Several studies have during the past fifteen years been conducted on the seismic noise field at the NORSAR / NORESS array sites. These investigations have revealed systematic diurnal and seasonal variations in the seismic noise level (Fyen, 1988; Ringdal and Bungum, 1977). Bungum et al (1985) found that the short-period noise field at NORSAR was dominated by westerly directions for frequencies at 1 Hz and below, whereas easterly directions dominated the noise field above 2 Hz. It has also been shown that from time to time there is a significant increase in the noise variance which results in an increased number of false alarms triggered by the automatic signal detector (Steinert et al, 1975). In this study we will report on the directional and temporal distribution of the short-term noise fluctuations. We will correlate the temporal distribution with environmental factors and attempt to locate possible noise sources.

Real-time processing results

The algorithm for real-time processing of data from the NORESS array has been described in detail by Mykkeltveit and Bungum (1984). A conventional STA/LTA detector is applied to a set of 17 coherent and 3 incoherent filtered array beams. For further information on incoherent beamforming, see Ringdal et al (1975). When a detection is declared, the refined arrival time and the dominant signal frequency are estimated. Narrow-band frequency-wavenumber analysis (Capon, 1969) is then performed to estimate the apparent velocity and azimuth of the detected phase. The automatic event location procedure is based on the S-P travel time difference and the azimuth of one of the phases. The P- and S-phases are automatically separated by their apparent velocity estimates (above and below 6.0 km/s, respectively), and are associated to the same event if the estimated azimuths differ by less than a predefined value. The data investigated in this paper are the reports produced by the real-time processor, which contain arrival time, definition of the detection beam, dominant frequency, signal-to-noise ratio, apparent velocity and azimuth for each detected phase. The main topic of interest in the context of this study is the occasional occurrence of a vast increase (sometimes lasting for several days) in the number of detections on the incoherent beams.

In most cases the associated apparent velocities are less than 3.0 km/s and unlike the local and regional S-waves, there is no sign of P-detections preceding these phases. When sorting the processing reports according to the apparent velocities of the detected phases, we found for the year 1986 that 15406 out of a total number of 49891 detections had apparent velocities less than 3.0 km/s. The numbers for the year

1987 were 22087 and 50665, respectively. The majority of the low-velocity detections have low signal-to-noise ratios and could be avoided if the detection threshold on the incoherent beams were raised. But the incoherent beams are our best tool for detecting local and regional secondary phases, so raising the threshold would imply missing a lot of interesting secondary phases.

Azimuthal distribution

Figs. VII.2.1a and 1b are histograms showing the azimuthal distribution of the low-velocity detections for 1986 and 1987. The distributions are very similar with a dominant region between 5 and 120 degrees azimuth and a peak between 95 and 105 degrees. Few low-velocity arrivals come from the southern direction, and two minor peaks show up at about 250 and 320 degrees azimuth. It should also be emphasized that 1987 had about 6500 more low-velocity detections than 1986 and that most of these 6500 were confined to the major dominant azimuth range (95-105 degrees).

Temporal distribution

The majority of the low-velocity detections have peak frequencies between 2 and 3 Hz. Fyen (1988) found that there was an increase in the 3 Hz noise level coinciding with increased water flow in the nearby river Glomma. Fig. VII.2.2 shows a map of the NORESS site, the nearby populated areas and the river Glomma. In Fig. VII.2.3a we have displayed the distribution within the year 1986 of the low-velocity detections with azimuths between 95 and 105 degrees, and in Fig. VII.2.3b the corresponding distribution of the water flow in river Glomma. The correlation between these histograms is obvious. The maxima at about day 230 and day 300 coincide, but the major detection peak starting at day 130 is somewhat delayed relative to the water flow maximum. The equivalent annual distributions for 1987 are given in Figs. VII.2.4a and 4b. In contrast to 1986, there was during the autumn of 1987 a large flood due to heavy rain for more than a week, and this is also reflected in a peak in the number of detections. Also in this case, the largest detection peaks at about day 190 and day 300 are delayed relative to the water flow maxima and they seem to occur with the decrease in the water flow.

In order to investigate further the stability of the noise field, a 6-hour interval containing numerous low-velocity detections were subjected to additional analysis by the wide-band frequency-wavenumber method desribed by Kværna and Doornbos (1986). A total of 720 time samples, each of 25 seconds length, were processed in the frequency band 2.5 to 2.9 Hz. Excluding the relatively few time samples with other types of signals, we obtained a mean azimuth of 99.5 degrees with a standard deviation of 0.8 degrees. The mean apparent velocity was 2.83 km/s with a standard deviation of 0.03 km/s. Thus, there is a continuous background noise field within this frequency band with fluctuations causing the low-velocity detections.

We also investigated the time-dependency of low-velocity detections at other azimuths. We found that the temporal distributions of low-velocity detections with azimuths between 0 and 95 degrees were rather flat and did not reveal any particular peaks during the year. The same applies to the detections with azimuths between 300 and 330 degrees. Thus the only definite correlation with water flow occurred in the 95-105 degree range.

Discussion and conclusions

The short term variability of seismic noise recorded at NORESS has been characterized in this paper by observing the distribution of array detections triggered by the short-term to long-term "linear power" ratio. The cumulative frequency distribution of these detections has been computed as a function of signal-to-noise ratio. The slope of the log(SNR) versus log (number of detections) relationship at low SNR values is 6.7 for the year 1987, see Fig. VII.2.5. This is significantly greater than the value near 1.0 normally associated with earthquakes (see, e.g., Steinert et al, 1975). This observation, in conjunction with the observed low apparent velocities and the absence of associated P-phase detections, indicates that these low SNR detections generally do not originate from tectonic events or explosions, and are thus part of the ambient noise field.

Our results show typical Rayleigh wave velocities (2.5-3.0 km/s) and dominant frequencies between 2 and 3 Hz for the vast majority of these detections. The azimuthal distribution of the detections is remarkably similar for the two years 1986 and 1987, with a dominance of phases from the easterly direction. This corresponds to the direction to the large nearby river Glomma, and thus indicates that the water flow in this river directly or indirectly is strongly associated with such noise fluctuations.

A particularly good correlation has been found between the number of Rayleigh wave detections in the azimuth range 95-105 degrees (which has the most detections for either year) and the Glomma water flow. In fact, during periods of heavy water flow, the noise field is continuously dominated by propagating Rayleigh waves from this particular direction. This implies that there is a continuous source of these disturbances. Tracing in the previously found direction of 99.5 degrees from NORESS, we find at the river Glomma, near the town of Braskereidfoss, a dam construction and a hydroelectric power plant.

Bungum et al (1977) conducted a study of propagating seismic phases from a similar source, the hydroelectric power plant at Hunderfossen near NORSAR subarray 14C. The concluded that this plant produced continuous strong seismic energy at 2.778 Hz frequency and S-phase velocity (3-5 km/s). It is interesting that in our case we observe similar signal frequencies, but significantly lower phase velocities. In fact, one of the unique capabilities of the NORESS system is the ability to provide very reliable phase velocity and directional measurements, and the uncertainty in our phase velocity estimates is extremely small (only 0.03 km/s for the 6-hour period analyzed in detail). We also note that apart from the mentioned azimuth range, we have found no particular correspondence between water flow and the number of detections. Also an unresolved question is why the majority of detections in the azimuth range 95-105 degrees occur with a slight delay (3-5 days) after the Glomma water flow peaks. The diurnal distribution of the low-velocity detections have minima during working hours. This can be explained in terms of the increased noise level at these time intervals, as documented by Fyen (1988).

In conclusion, this study has documented that the main source of short-term variability in the seismic noise at NORESS, i.e., noise bursts of a few seconds duration, are propagating Rayleigh waves of frequencies between 2 and 3 Hz. In contrast to the lower frequency noise which is dominated by microseisms associated with storm activity in the North Atlantic Ocean in the westerly direction from NORESS, these Rayleigh waves mostly originate east of the array. To a large extent, the observed detections are strongly correlated with the water flow in the nearby river Glomma, but the exact determination of the actual source and the generation mechanisms will require further study.

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References

Bungum, H., S. Mykkeltveit and T. Kværna (1985): Seismic noise in Fennoscandia, with emphasis on high frequencies. Bull. Seism. Soc. Am., 75, 1489-1513.

Bungum, H., T. Risbo and E. Hjortenberg (1977): Precise continuous monitoring of seismic velocity variations and their possible connection to solid earth tides. J. Geophys. Res., 82, 5365-5373.

Capon, J. (1969): High-resolutiohn frequency-wavenumber spectrum analysis. Proc. IEEE, 57, 1408-1418.

Fyen, J. (1988): Diurnal and seasonal variations in the microseismic noise level observed at the NORESS array. Manuscript submitted to Phys. Earth Planet. Inter.

Kværna, T. and D.J. Doornbos (1986): An integrated approach to slowness analysis with arrays and three-component stations. Semiann. Tech. Summary, 1 Oct 1985 - 31 Mar 1986, NORSAR Sci. Rep. No. 2-85/86, Kjeller, Norway.

Kværna, T., S. Kibsgaard and F. Ringdal (1987): False alarm statistics and threshold determination for regional event detection. Semiann. Tech. Summ., 1 Apr - 30 Sep 1987, NORSAR Sci. Rep. No. 1-87/88, Kjeller, Norway.

Mykkeltveit, S. and H. Bungum (1984): Processing of regional events using data from small-aperture arrays. Bull. Seism. Soc. Am., 74, 2313-2333.

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

Ringdal, F., E.S. Husebye and A. Dahle (1975): P-wave envelope representation in event detection using array data. In: K.G. Beauchamp (ed.), Exploitation of Seismograph Networks. Nordhoff-Leiden, The Netherlands, 353-372.

Steinert, O., E.S. Husebye and H. Gjøystdal (1975): Noise variance fluctuations and earthquake detectability. Geophys. J. R. astr. Soc., 41, 298-302.

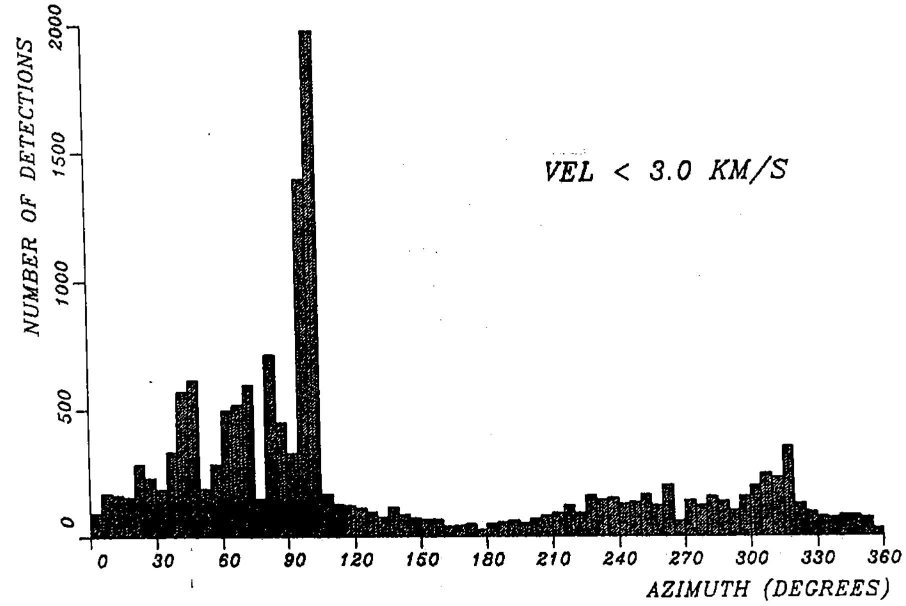

Fig. VII.2.1a Histogram showing the azimuthal distribution of NORESS low-velocity detections for the year 1986. The azimuth solutions have been estimated by the frequency-wavenumber method of Capon (1969). The bar width is five degrees.

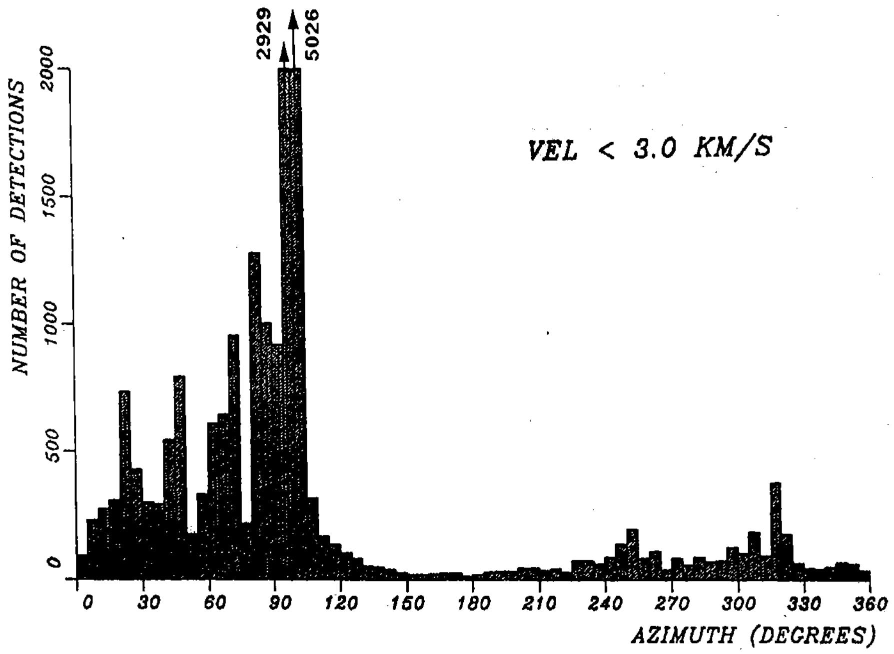

Figure VII.2.1b Same as Fig. VII.2.1a, but for the year 1987.

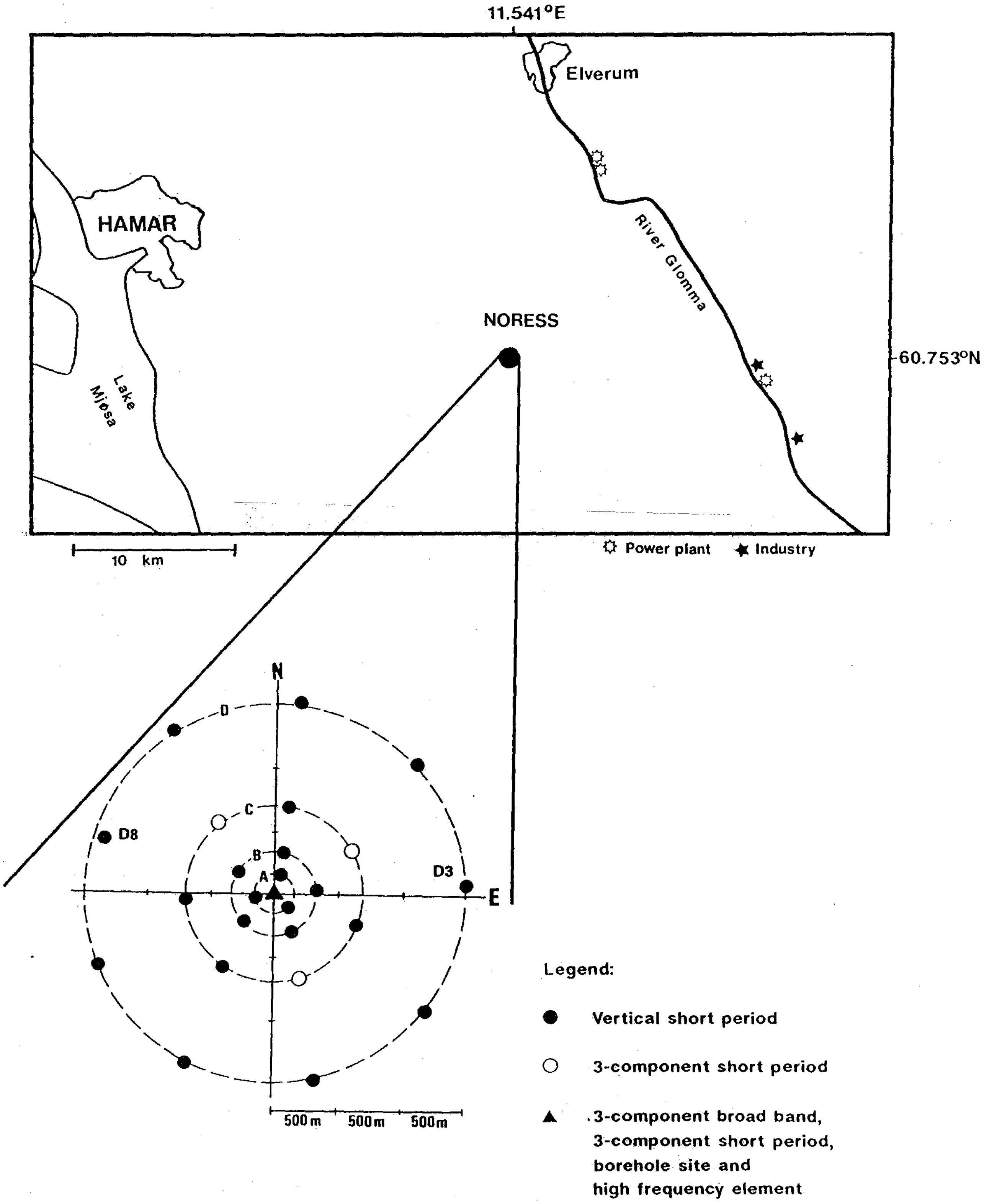

Fig. VII.2.2 Map of the area surrounding the NORESS array, with nearby populated areas, industry sites and the river Glomma specially marked. The geometry of NORESS is also shown.

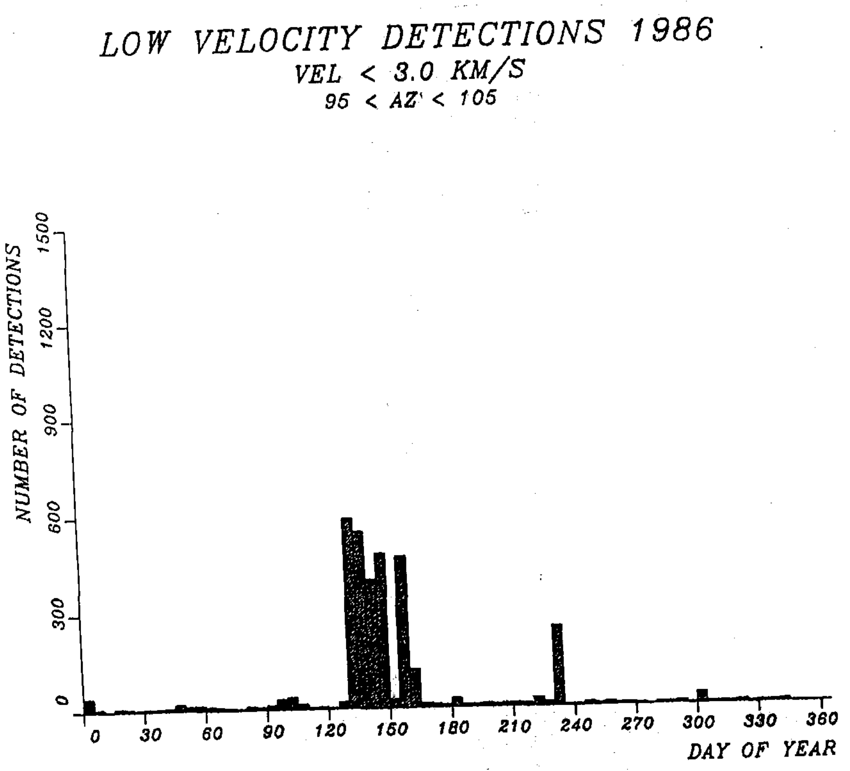

Fig. VII.2.3a Histogram showing the distribution of NORESS low-velocity detections in the azimuth range 95-105 degrees during the year 1986. Each bar gives the number of detections in a five-day period.

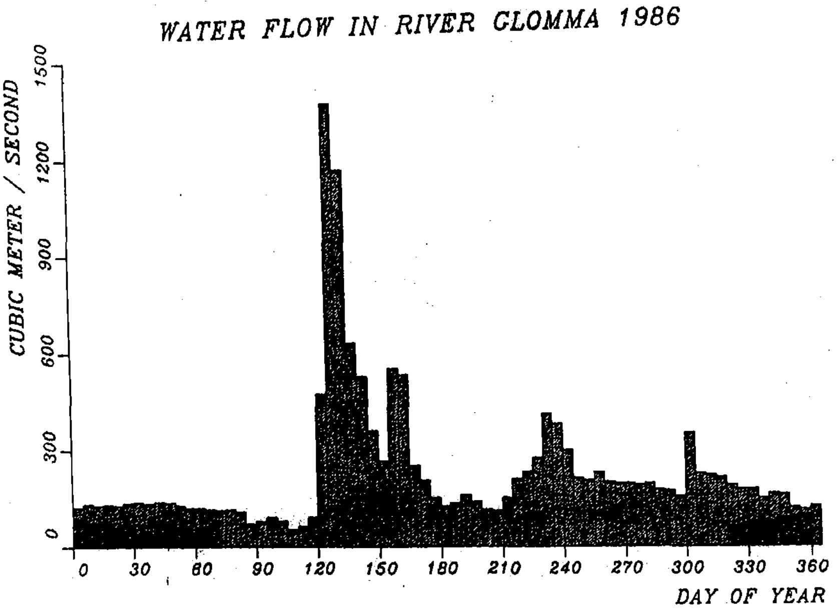

Fig. VII.2.3b Histogram showing the distribution of water flow in river Glomma measured at the town of Elverum (see Fig. VII.2.2) for the year 1986. Each bar corresponds to a five-day average value.

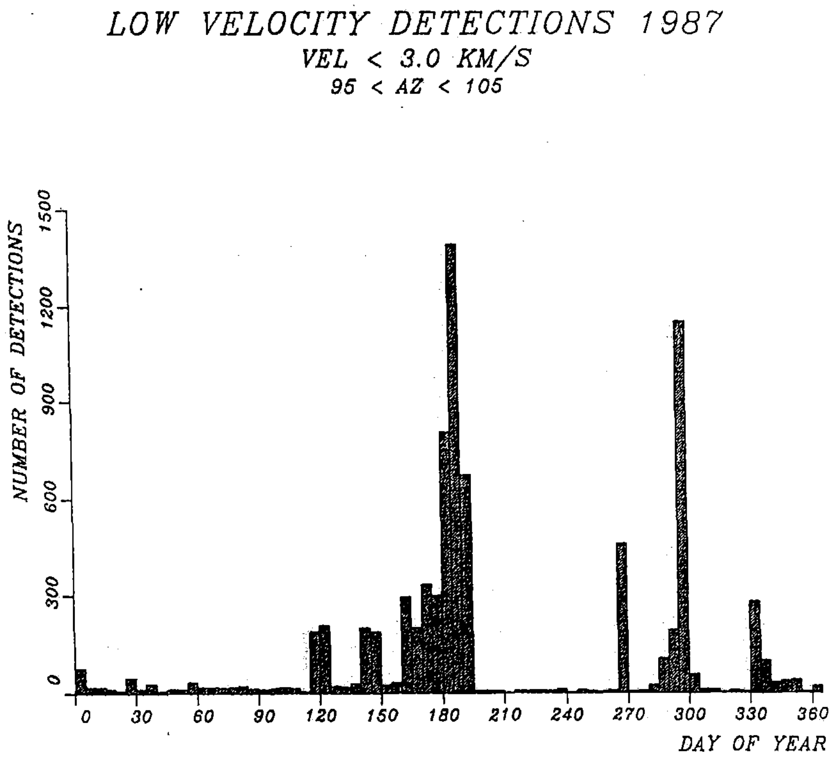

Fig. VII.2.4a The same as for Fig. VII.2.3a, but for the year 1987.

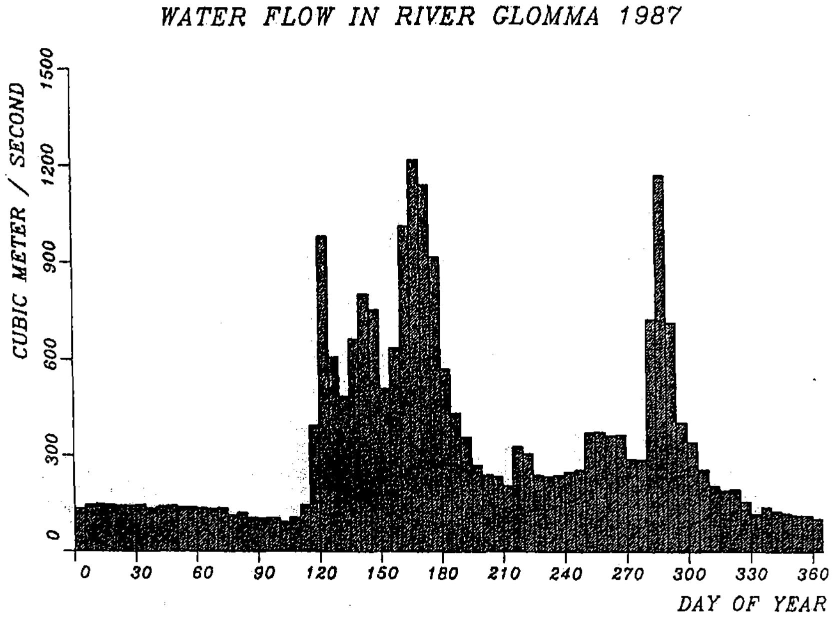

Fig. VII.2.4b The same as for Fig. VII.2.3b, but for the year 1987.

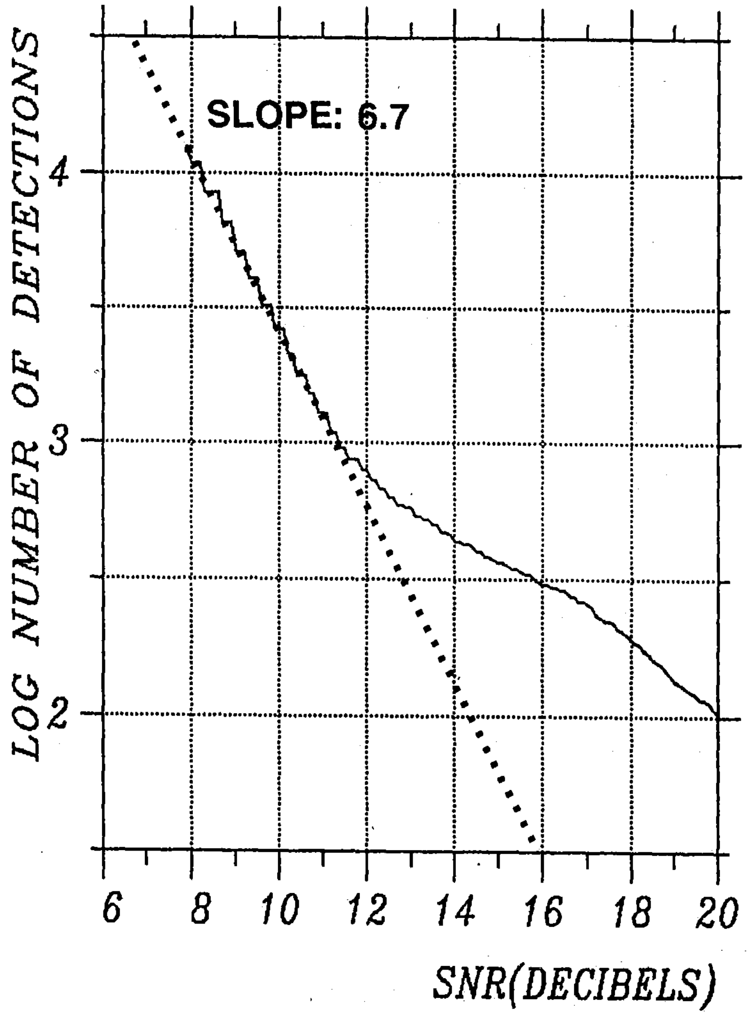

Fig. VII.2.5 Cumulative distribution during 1987 of number of detections versus signal-to-noise ratio for an incoherent NORESS beam filtered in the frequency band 2.0-3.0 Hz. The slope of the log(SNR) versus log(number of detections) relationship at low SNR give some indication on the mechanisms causing these detections (see Steinert et al, 1975; Kværna et al, 1987).