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7.4 Continuous threshold monitoring of the Novaya Zemlya test site

Introduction

The continuous threshold monitoring technique (Ringdal and Kværna, 1989) represents a new approach toward achieving reliable seismic monitoring for the purpose of verifying nuclear test ban treaties.

Traditionally, seismic monitoring has relied upon applying signal detectors to individual stations within a monitoring network, associating detected phases and locating possible events in the region of interest. This procedure has been accompanied by assessments of network capabilities for the target region, usually by applying statistical models for the noise level distribution, introducing station corrections for signal attenuation and devising a combinational procedure to determine the detection threshold as a function of the number of phase detections required for reliable location.

The statistical noise models used in these capability assessments are not able to accommodate the effect of interfering signals, such as the coda of large earthquakes, which may cause the estimated thresholds to be quite unrealistic at times. Furthermore, only a statistical capability assessment is achieved, and no indication is given as to particular time intervals when the possibility of undetected clandestine explosions is particularly high.

The continuous threshold monitoring technique alleviates all of these problems. It makes it possible to ascertain, at any point in time, for a given target region, the maximum magnitude of a possible clandestine explosion at a predefined level of confidence. This makes it possible to focus attention upon those specific time intervals when realistic evasion opportunities exist, while retaining confidence that no treaty violation has occurred at other times.

Application to the Novaya Zemlya test site

In order to demonstrate how such monitoring could be performed in a practical operational situation, we have conducted an experiment during which we have applied continuous threshold monitoring to the Novaya Zemlya test site for a full one-week period. Our data base has been the Fennoscandian regional array network (NORESS, ARCESS, FINESA). As illustrated in Fig. 7.4.1, these three arrays are all within regional distances from the test site, with excellent P-phase detection capabilities (Fig. 7.4.2). The ARCESS array also detects S phases from Novaya Zemlya explosions quite well, whereas NORESS and FINESA have a lower S-phase detection capability.

The parameters used in the threshold monitoring experiment are given in Table 7.4.1. For each array, we steer "optimum" P and S beams towards the test site, and calibrate these beams using actually observed signal attenuation from Novaya Zemlya explosions. By focusing in this way on the target region, we can at any point in time measure the "noise magnitude" for a given phase at a given array, and combine these data to obtain a network threshold as explained in detail by Ringdal and Kværna (1989).

Results

Figs. 7.4.3–7.4.9 show the result of the monitoring experiment. Each of these figures covers one data day, starting 24 October 1990. The upper three traces of each figure represent the thresholds (i.e., 90 % upper magnitude limits) obtained from the three individual arrays, whereas the bottom trace illustrates the network threshold. Typically, the individual array traces have a number of significant peaks for each 24-hour period, due to interfering events (local or teleseismic). On the network trace, the number and sizes of these peaks are greatly reduced, because an interfering event will usually not provide matching signals at all the stations. From probabilistic considerations, it can in such cases be inferred that the actual network threshold is lower than these individual peaks might indicate.

On each of the one-day figures, we have included comments explaining the presence of the most significant peaks on the network trace. Here, we will just note that the first day, 24 October 1990, was the day of an actual nuclear explosion (m_b = 5.7) on Novaya Zemlya, and this event naturally stands out on the plot. While the peak value of the network threshold plot does not represent the actual magnitude of the event, it is in fact quite close (5.64).

As a general comment to Figs. 7.4.3–7.4.9, we note that such plots, which are easily generated by the Intelligent Monitoring System (IMS) (Bache *et al*, 1990), will enable the analyst to obtain an instant assessment of the actual threshold level of the monitoring network. The peaks on the network traces may be quickly correlated with the IMS detection bulletin, in order to decide whether they originate from interfering events or from events in the target region.

Discussion

In a monitoring situation, it will be important to isolate and analyze more extensively those time intervals which offer significant evasion opportunities. Table 7.4.2 gives a statistic of the number of occasions during which the upper magnitude limit exceeded a given level. In theory, if this limit is, e.g., at 3.0, it might be possible that a clandestine m_b = 3.0 explosion had occurred without being detected. There are many options available to investigate such a hypothesis in more detail, although we have not attempted to do so in this study. The most immediate approach would be to analyze high-frequency signals for the time interval being considered. For example, on ARCESS records Novaya Zemlya explosions will contain significant energy at 10 Hz and above, even at magnitudes well below 3.0. Teleseismic events, even of large m_b, will not contain much energy at these frequencies and thus it might be possible to obtain additional indications from these data.

To assess interfering phases from events at regional distances is more difficult, since the high-frequency energy might not discriminate such events from Novaya Zemlya explosions. In such cases, additional procedures, such as maximum likelihood beamforming, might become useful to suppress signals from the interfering event and thereby obtain a more realistic estimate of the signal energy arriving from the target region.

It is significant that the 3-array network studied in this paper can monitor the Novaya Zemlya test site down to m_b 2.5 or below more than 99 % of the time (Fig. 7.4.10). Further improvements would clearly be possible by adding more stations to the monitoring network, especially highly sensitive stations at other azimuths than those covered by the Fennoscandian network. This would in particular contribute to lowering the peaks due to interfering events, whereas any event truly originating in the target region would of course still stand out clearly on the combined network traces.

In conclusion, the continuous threshold monitoring has been demonstrated to provide a simple and very effective tool in day-to-day monitoring of a site of particular interest. Further research will focus upon developing methods to analyze time intervals during which significant evasion possiblities might exist. Data from the regional arrays, the large-aperture NORSAR arrray, as well as other available stations, will be used in these analyses.

T. Kværna
F. Ringdal

References

Bache, T.C., S.R. Bratt, J. Wang, R.M. Fung, C. Kobryn and J. Given (1990): The Intelligent Monitoring System, *Bull. Seism. Soc. Am.*, Special Issue, in print.

Ringdal, F. and T. Kværna (1989): A multichannel processing approach to real time network detection, phase association and threshold monitoring, *Bull. Seism. Soc. Am.*, 79, 1927–1940.

Station	Phase	Tr. Time	App. Vel.	Azim.	Filter	Config.	STA_len.	Tim. Tol.	Sta_Calib
ARC	Pn	148.0	9.9	60.5	3.0–5.0	A0,B,C,D	2.0	2.0	0.754
ARC	Sn	257.0	4.9	53.2	3.0–5.0	A0,B,C,D	5.0	3.0	1.176
FIN	P	228.0	9.6	32.9	2.0–4.0	A0,B,C,	2.0	2.0	1.520
NRS	P	284.0	10.4	28.1	1.5–3.5	A0,B,C,D	2.0	2.0	0.677

Tr. time	—	Travel time of phase
App. vel.	—	Apparent velocity from broadband F-K measurement
Azim.	—	Azimuth from broadband F-K measurement
Filter	—	Cutoffs of bandpass filter (3rd order Butterworth)
Config.	—	Array configuration used in beamforming. A0,B,C means A0Z, B-ring and C-ring
STA_len.	—	STA length in seconds
Tim. tol.	—	Time tolerance when searching for maximum STA
STA_calib.	—	Calibration factor used when converting STA values (in quantum units) to magnitude. Magnitude = log10(STA) + STA_calib.

Table 7.4.1.

	Day-of-Year							Total
	297	298	299	300	301	302	303	(one week)
$m_b \geq 4.0$	1	0	0	0	0	0	0	1
$m_b \geq 3.5$	1	1	0	0	0	0	0	2
$m_b \geq 3.0$	3	2	2	0	0	0	0	7
$m_b \geq 2.5$	5	12	5	0	3	6	3	34

Table 7.4.2. Statistics of peaks in the network threshold traces. See also comments on Figs. 7.4.3–7.4.9.

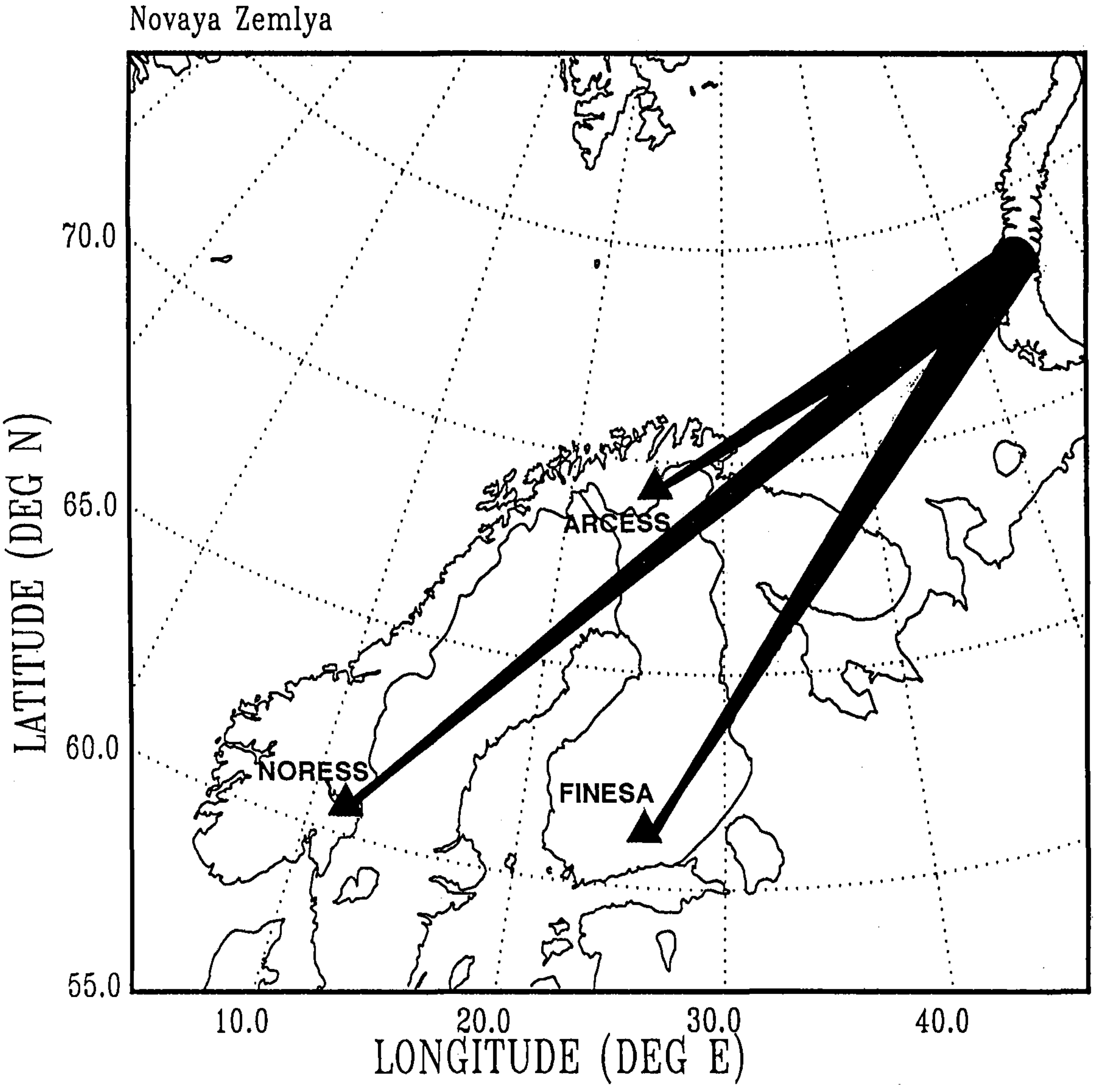

Fig. 7.4.1. Location of the target area (Novaya Zemlya) for the threshold monitoring experiment. The locations of the three arrays NORESS ($\Delta = 2280$ km), ARCESS ($\Delta = 1110$ km) and FINESA ($\Delta = 1780$ km) are indicated.

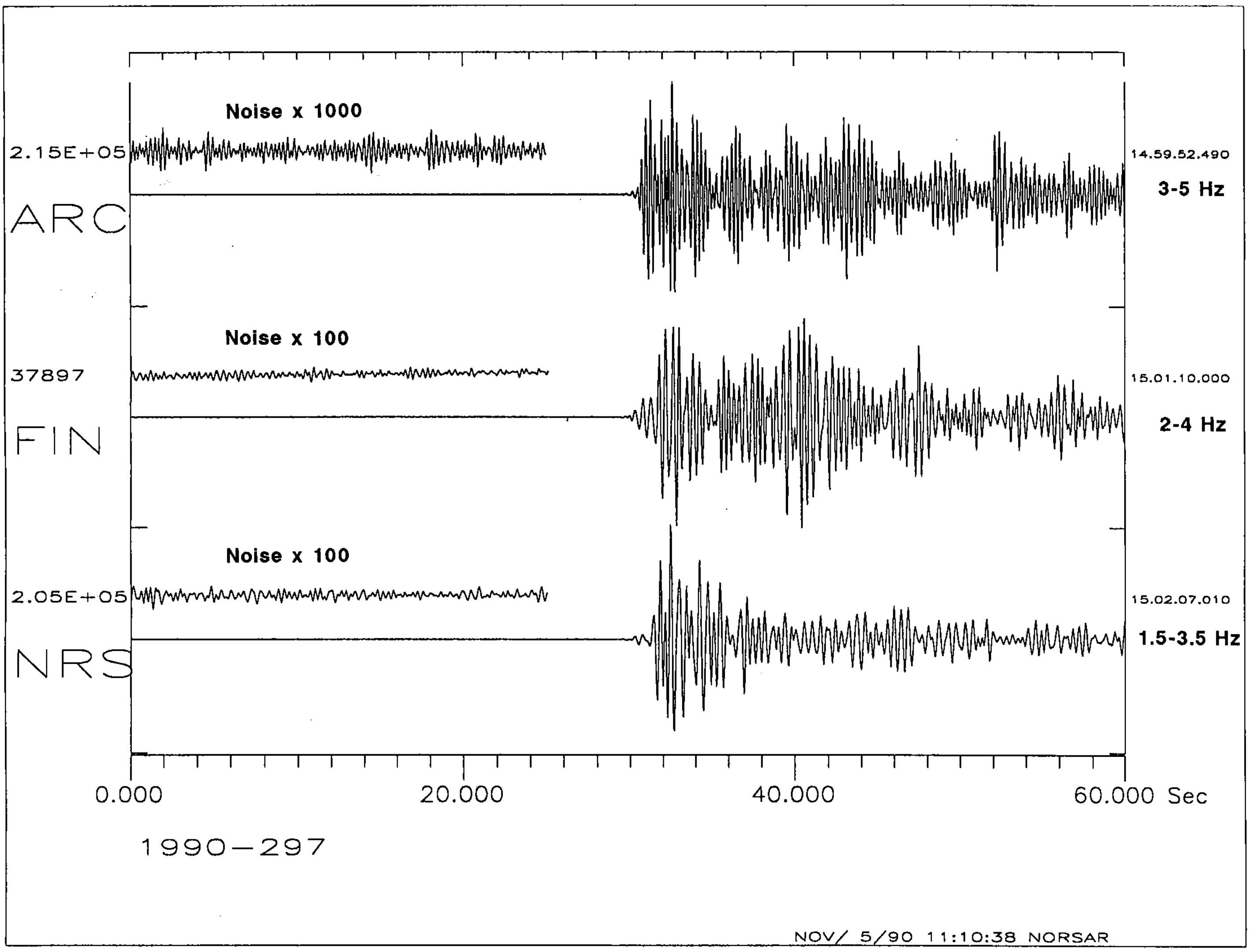

Fig. 7.4.2. P-wave recordings (filtered array beams) at ARCESS, FINESA and NORESS for the Novaya Zemlya nuclear explosion 24 October 1990. To illustrate the high signal-to-noise ratios, noise traces scaled by factors of 1000 (ARCESS) and 100 (FINESA and NORESS) are displayed for each array.

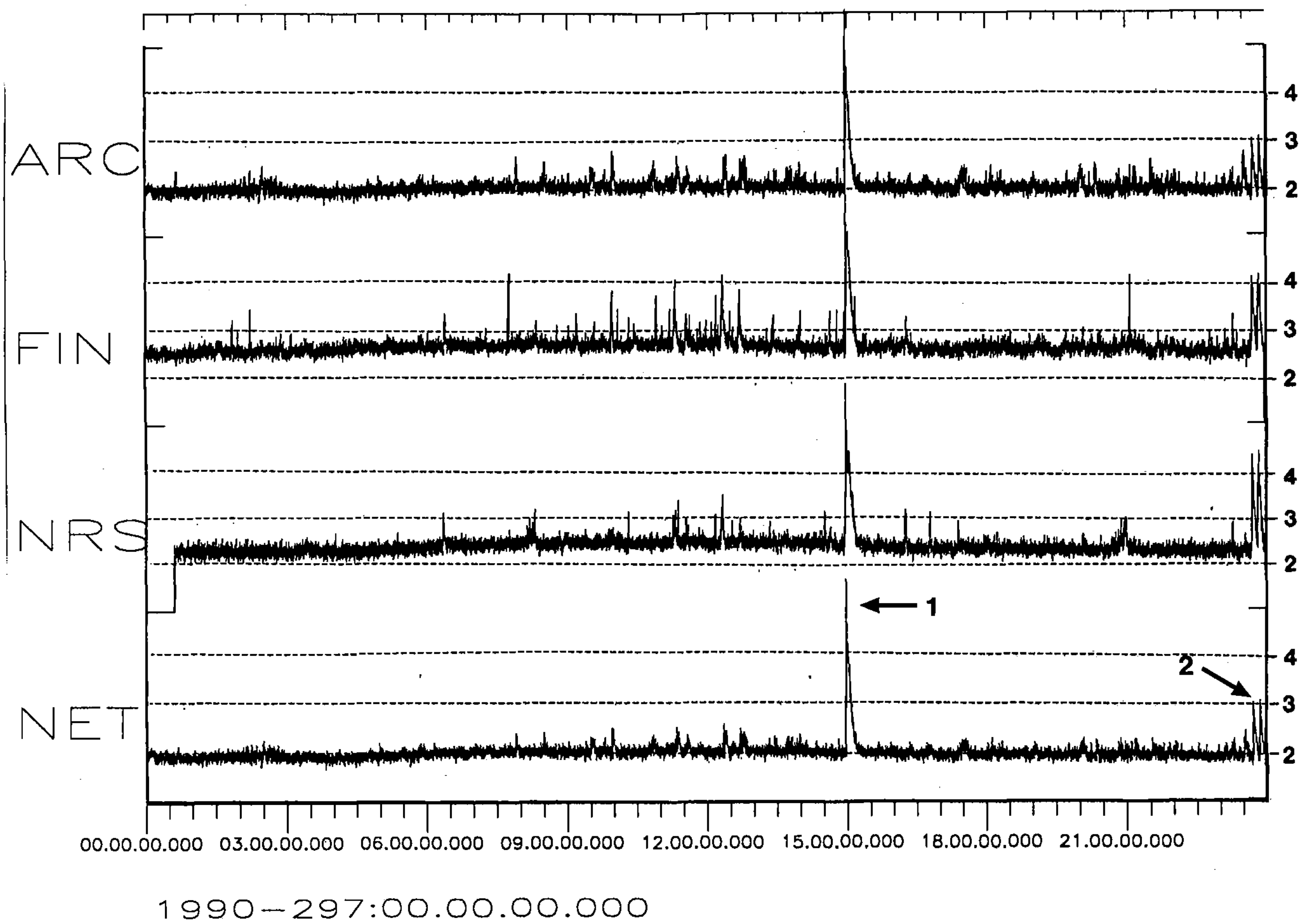

Fig. 7.4.3. Threshold monitoring of the Novaya Zemlya test site for day 297 (24 October 1990). The top three traces represent thresholds (upper 90 per cent magnitude limits) obtained from each of the three arrays (ARCESS, FINESA, NORESS), whereas the bottom trace shows the combined network thresholds.

Notes:

1. An underground nuclear explosion (m_b = 5.7) at Novaya Zemlya at 14.58.00 GMT. The peak of the network trace is 5.64.
2. Two teleseismic earthquakes from N. Xinjang province, China (m_b = 5.2 and 5.4). The P-wave train from each of these earthquakes causes the network threshold to increase to about m_b = 3.0 for the target region.

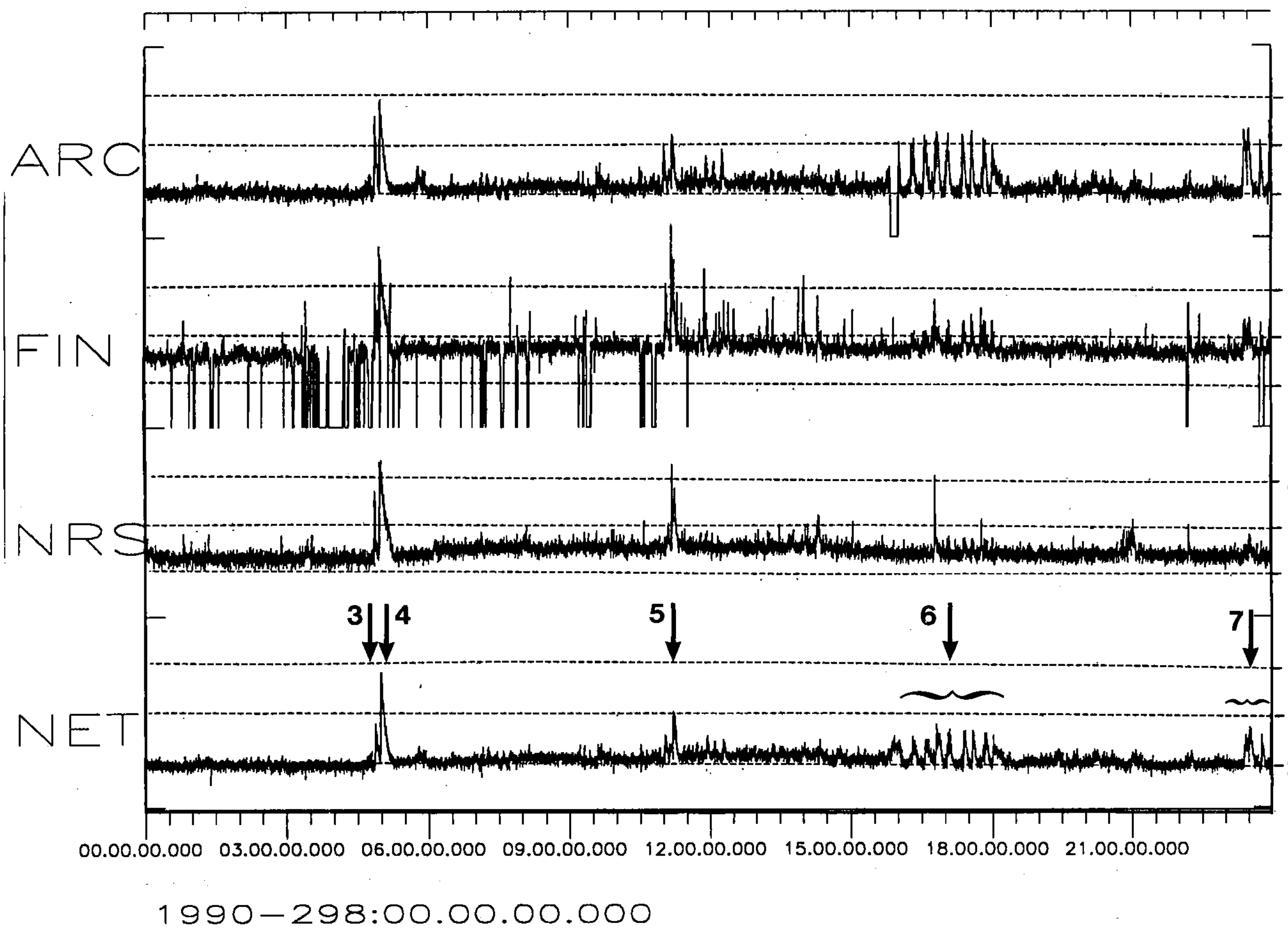

Fig. 7.4.4. Same as Fig. 7.4.3, but for day 298 (25 October 1990). The FINESA array had several short outages this day, but this caused no particular problems in terms of network threshold capacity.

Notes:

3. An earthquake (m_b = 4.5) near Jan Mayen. The corresponding network threshold peak for Novaya Zemlya is m_b=2.8.
4. A teleseismic earthquake (m_b = 6.0) at Hindu Kush. The relatively strong P-wave train caused a peak threshold of m_b = 3.8 for monitoring Novaya Zemlya.
5. A teleseismic earthquake (m_b = 5.9) at Mindanao, Philippine Islands. Corresponding threshold is m_b = 3.0.

6-7. A sequence of seismic events (presumably underwater explosions) near Murmansk, Kola Peninsula. The network threshold for monitoring Novaya Zemlya is about m_b = 2.5 to 2.8 at the times of these events.

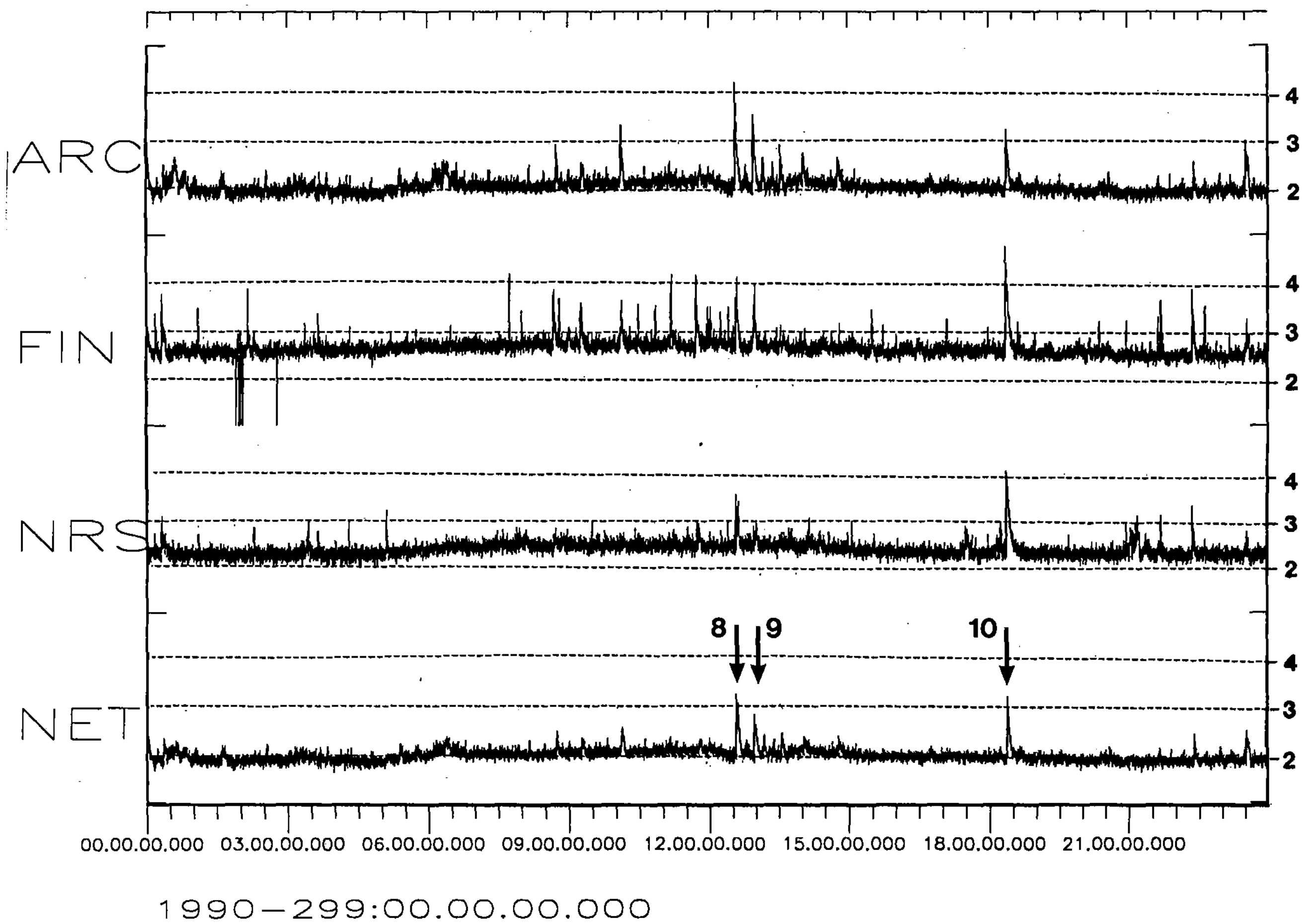

Fig. 7.4.5. Same as Fig. 7.4.3, but for day 299 (26 October 1990).

Notes:

8. A large mining explosion ($M_L = 3.0$) near the Norway–USSR border. The Novaya Zemlya threshold peak is $m_b = 3.2$. Note that this threshold exceeds the event magnitude; this is because of the proximity of the event to the network stations.
9. A large mining explosion ($M_L = 2.5$) at the Kola Peninsula. The Novaya Zemlya threshold peak is $m_b = 2.8$.
10. A teleseismic earthquake ($m_b = 5.1$) near Lake Baikal. The network threshold peak is $m_b = 3.2$.

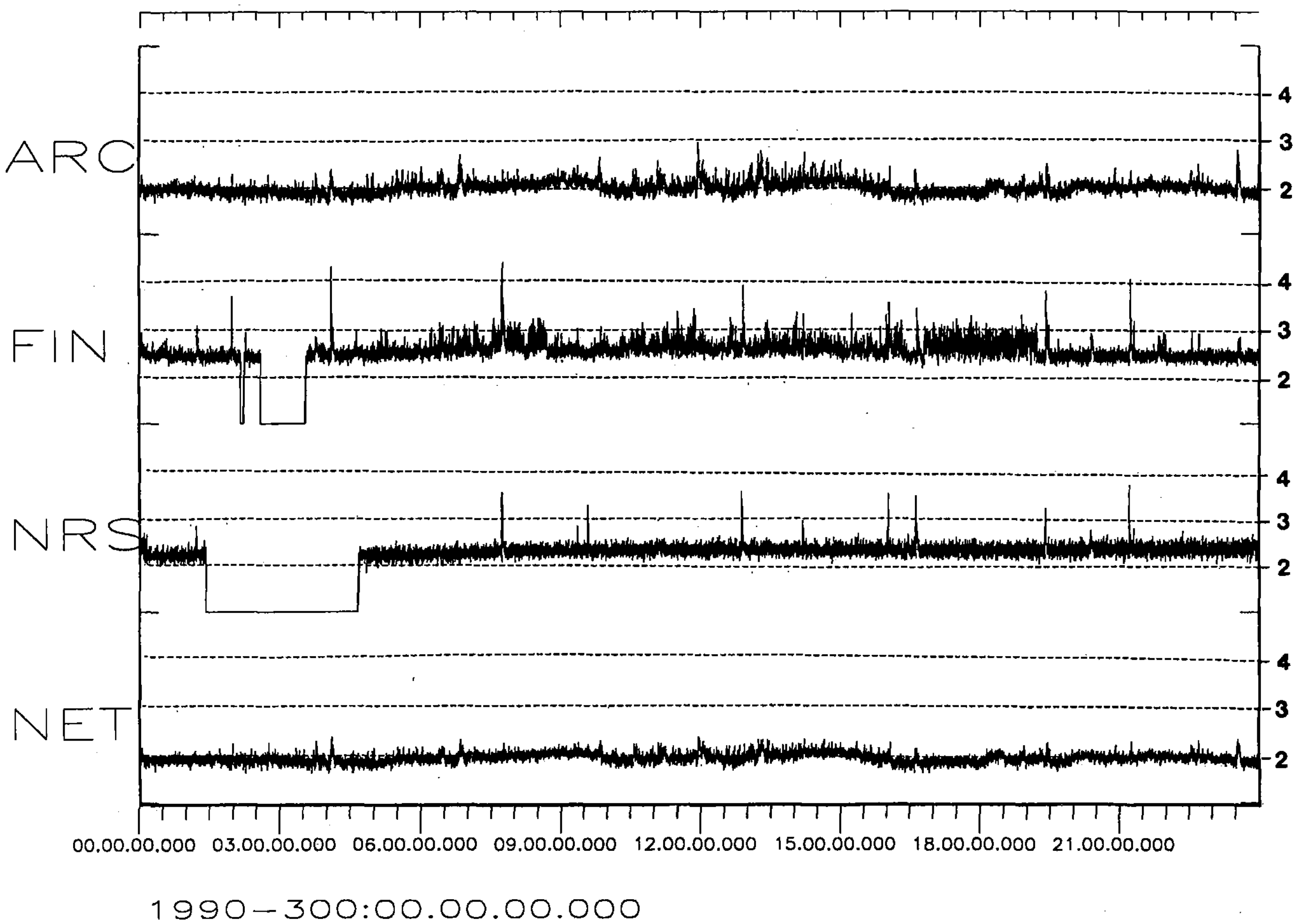

Fig. 7.4.6. Same as Fig. 7.4.3, but for day 300 (27 October 1990).

Notes:
No significant peak during this day. The simultaneous outages at FINESA and NORESS did not cause significant problems for the network threshold monitoring.

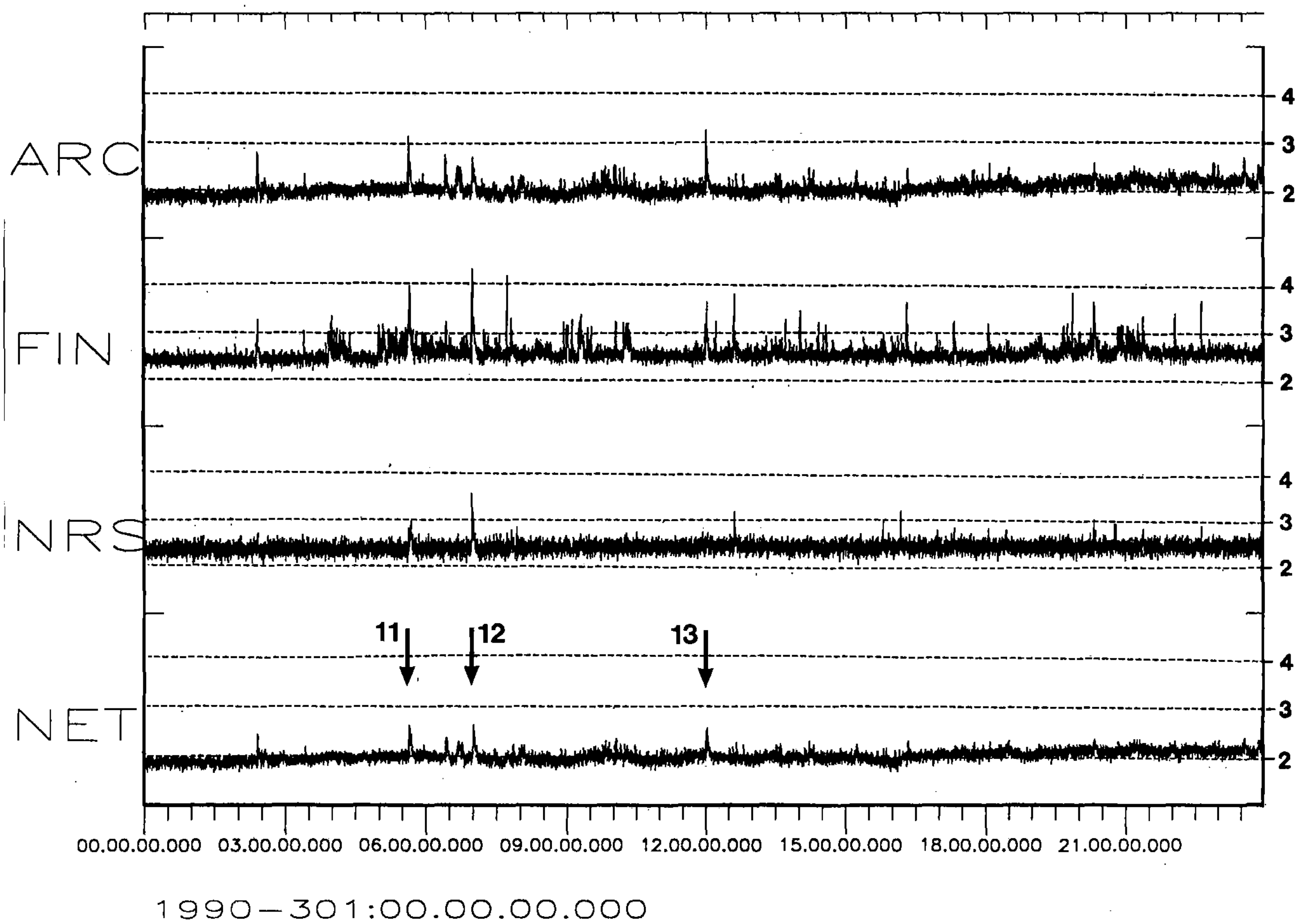

Fig. 7.4.7. Same as Fig. 7.4.3, but for day 301 (28 October 1990).

Notes:

11 and 13. Two large mining explosions ($M_L = 2.5$) on the Kola Peninsula. Network threshold is about $m_b = 2.6$.

12. A teleseismic earthquake ($m_b = 5.3$) at the Kurile Islands. Network threshold is $m_b = 2.7$.

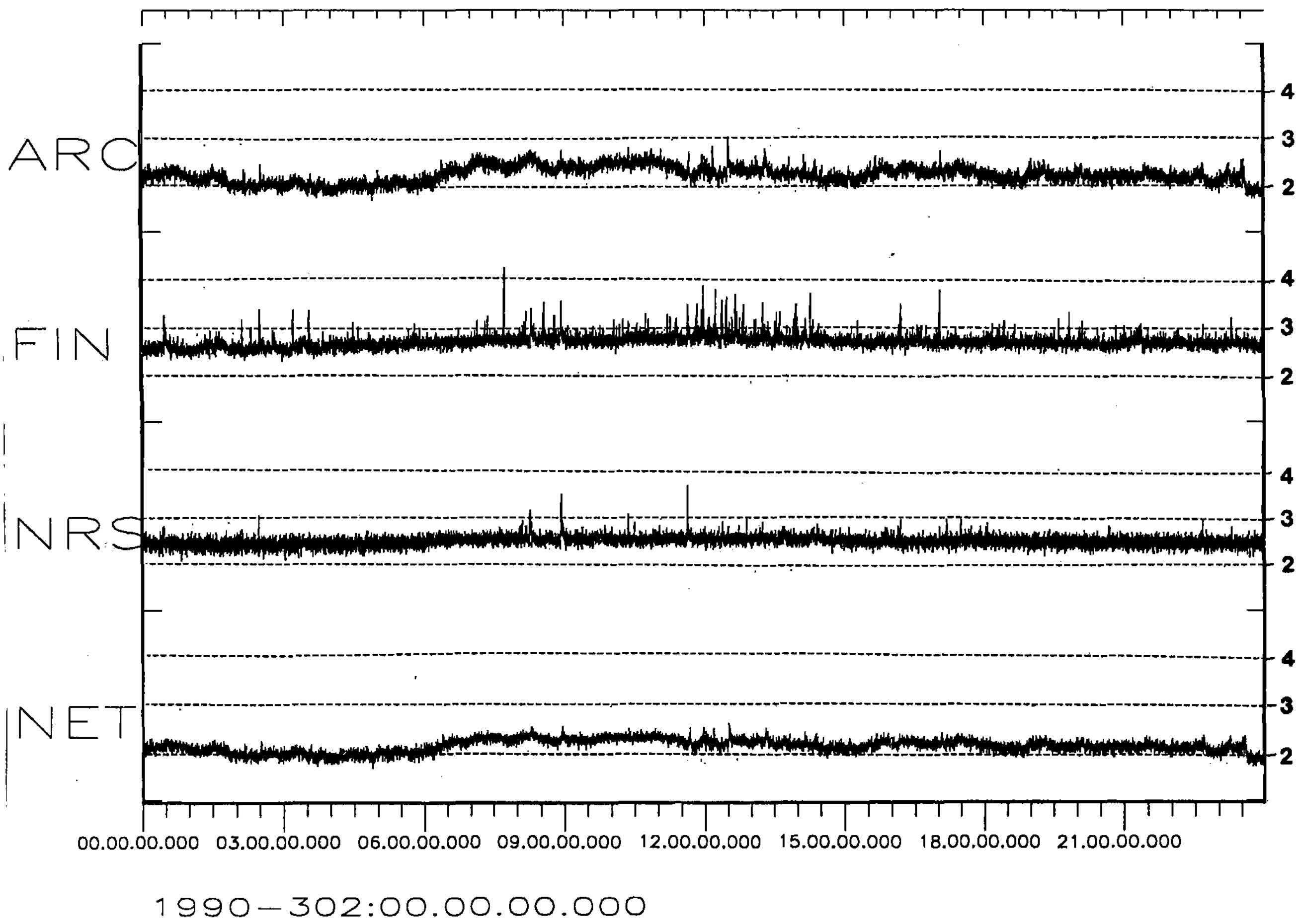

Fig. 7.4.8. Same as Fig. 7.4.3, but for day 302 (29 October 1990).

Notes:
No significant peaks in the network threshold plot this day.

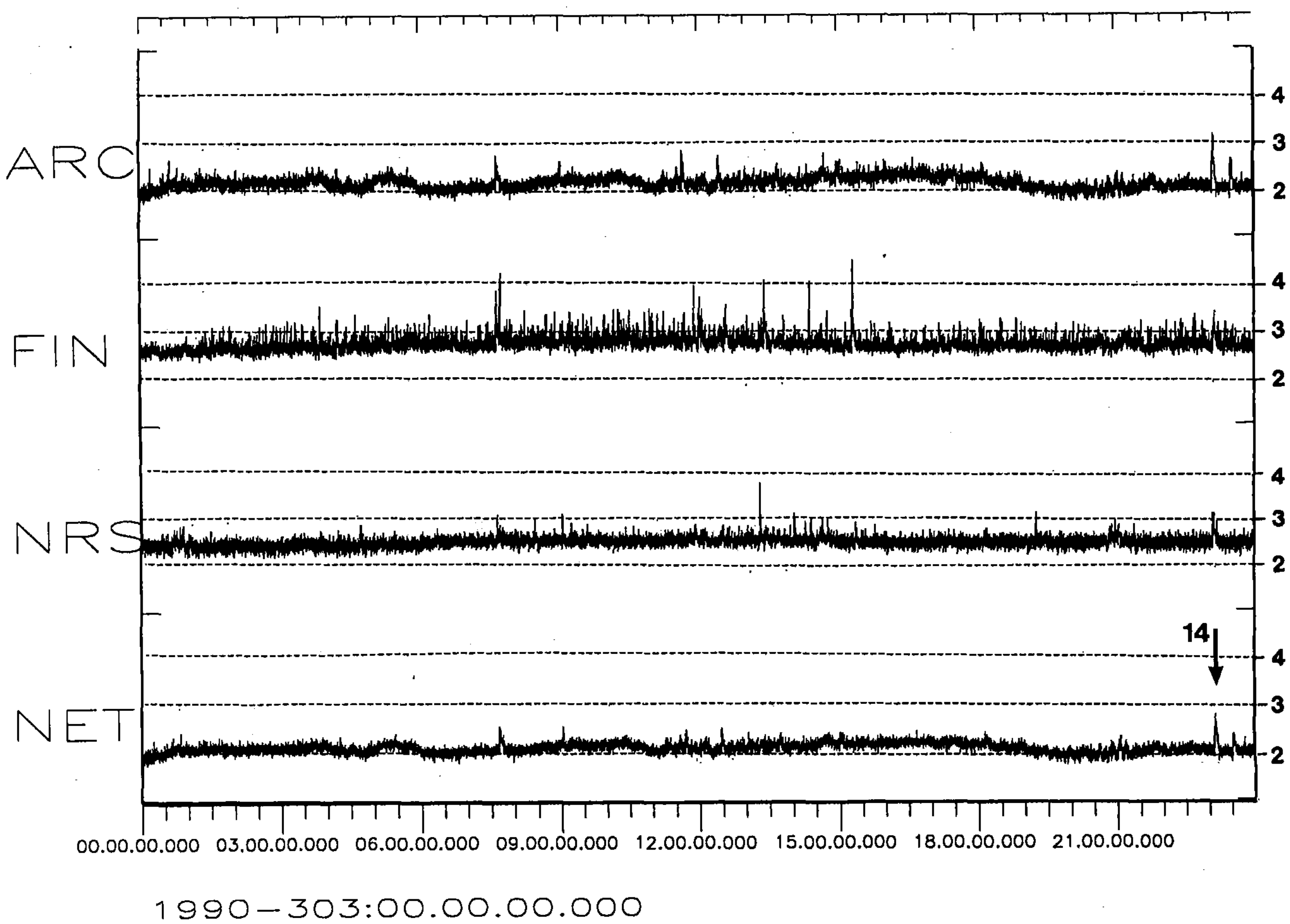

Fig. 7.4.9. Same as Fig. 7.4.3, but for day 303 (30 October 1990).

Notes:

14. A small earthquake ($M_L = 2.8$) in Nordland, N. Norway, caused an increase in the network threshold for Novaya Zemlya to $m_b = 2.8$.

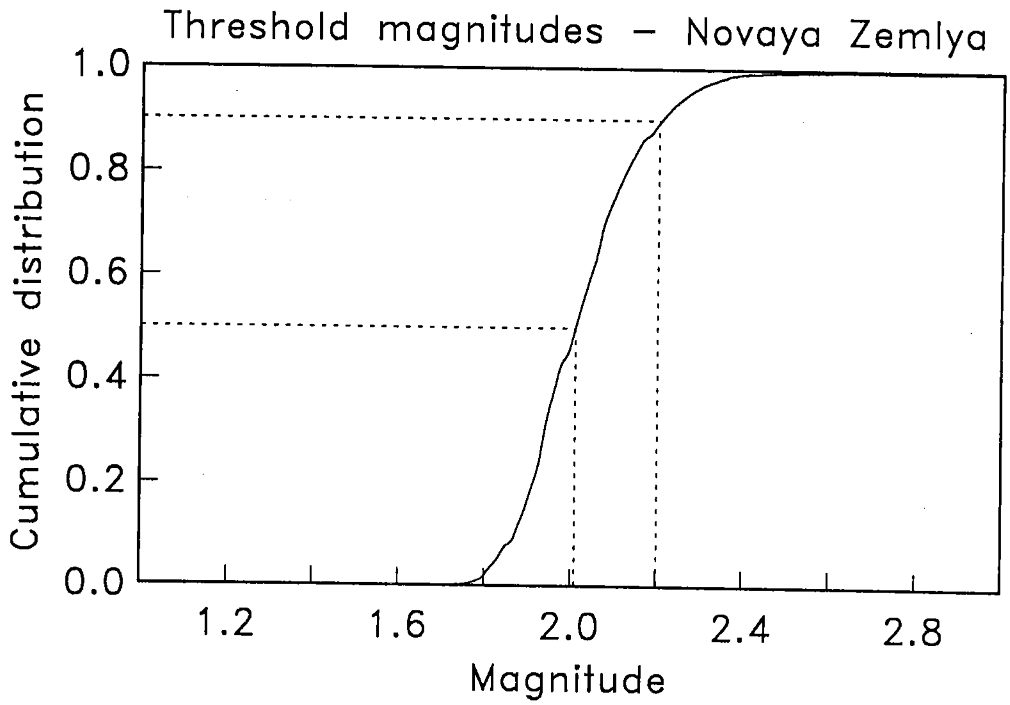

Fig. 7.4.10. Cumulative statistics of the network threshold magnitudes from Figs. 7.4.3–7.4.9, covering one full week of data.