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7.4 Monitoring a moratorium: An experiment in continuous seismic threshold monitoring of the northern Novaya Zemlya test site

Introduction

After 1 October 1992 a moratorium on nuclear testing has been in effect for the US, UK, Russia and France. On this background, we have applied the continuous threshold monitoring technique to the northern Novaya Zemlya test site for a full six-month period (1 October - 31 March 1993), using the NORESS, ARCESS and FINESA regional arrays. Starting 1 December 1992, we have compiled daily statistics of all peaks on the threshold diagram exceeding $m_b = 2.75$, and associated these peaks to regional or teleseismic events whenever possible. In addition, we have analyzed smaller peaks (below $m_b = 2.75$) that can possibly be associated with Novaya Zemlya epicenters.

The theoretical background for and applications of the continuous seismic threshold monitoring metod (CSTM) have been described in several articles. The approach was introduced by Ringdal and Kværna (1989), who showed that by continuously monitoring the seismic amplitude level at several seismic stations or arrays, one can at any time obtain an instant network-based magnitude threshold for a given target region. The magnitude threshold can be interpreted as the maximum magnitude of a possible clandestine explosion, given a predefined level of confidence. In the context of a comprehensive or threshold test ban treaty, the continuous assessment of the magnitude thresholds 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.

Previous results from experimental monitoring

Kværna (1992) presented results from a one-month experiment of continuously monitoring the northern Novaya Zemlya test site. Data from the Fennoscandian regional array network (ARCESS, FINESA, and NORESS), see Fig. 7.4.1, were used to calculate the magnitude thresholds. It was found that the test site could be consistently monitored at a very low magnitude level (typically $m_b = 2.5$). In fact, every occurrence of the threshold exceeding $m_b = 2.6$ could be explained as resulting from an identified interfering event signal either at teleseismic or regional distance, except for three instances when a short gap in ARCESS recording caused the network threshold to increase.

The excellent capability of the Fennoscandian regional array network to monitor the northern Novaya Zemlya test site was further confirmed by an experiment where recordings of the Novaya Zemlya nuclear test of October 24, 1990 were downscaled to $m_b = 2.6$ and superimposed on different noise intervals (Kværna, 1991).

In the context of using CSTM as a tool in routine monitoring, it is important to determine how the method will work under different conditions. Variability in the seismic noise level, occurrences of large earthquakes and aftershock sequences, station downtimes and data quality problems are all factors that will influence the performance of CSTM.

Analysis of network threshold peaks

Our monitoring experiment was conducted in the same way and with the same parameter settings as used by Kværna (1992). In Kværna (1992) the monitoring results were presented in terms of plots covering one data day each. In Figs. A-1 to A-29 of the Appendix of that report, each covering one day of February, 1992, all time periods where the network magnitude thresholds at the 90% confidence level exceeded $m_b = 2.6$ were identified. A similar approach was used for this experiment.

For the remainder of this paper, the term magnitude threshold implies the magnitude threshold at the 90% confidence level.

Figs. 7.4.2 shows a typical example of a one-day plot. The upper three traces of each figure represent the magnitude thresholds obtained from the three indivitual 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 signals from interfering events (regional or teleseismic). On the network trace, the number and sizes of these peaks are significantly reduced, because an interfering event usually will not provide matching signals at all stations. From probabilistic considerations, it can in such cases be inferred that the actual network threshold is lower than these individual peaks might indicate.

The arrows on the one-day threshold plots indicate peaks with network magnitude threshold exceeding $m_b = 2.75$. A **T** at the arrow indicates that the peak is caused by signals from a teleseismic event, whereas an **R** indicates signals from a regional or local event. Fig. 7.4.3 shows summary statistics for one data day, with an explanation of all threshold peaks exceeding 2.75. Such summary statistics were generated for each day during the four-month period, 1 December 1992 - 31 March 1993.

The peaks in the threshold traces are caused by either large teleseismic events or by regional events. The regional events were all processed and located by the Intelligent Monitoring System (IMS) (Bache et al., 1993), and the teleseismic events were located either by the IMS or by the QED service of the USGS.

Fig. 7.4.4 shows a histogram of the number of peaks exceeding given magnitude thresholds. During the entire four-month period, there were only 40 peaks exceeding $m_b = 3.0$. Each of these peaks could be unambiguously associated with either a regional or teleseismic event. Consequently, at the specified confidence level, we can state that no seismic event of $m_b > 3.0$ occurred at the test site during this four-month period.

The event at Novaya Zemlya on 31 December 1992

Figs. 7.4.5 and 7.4.6 show the threshold plots and peak statistics for 31 December 1992. At 0929 GMT that day, a peak occurred corresponding to an event at Novaya Zemlya, located by the IMS. This peak (which is the only one associated to a Novaya Zemlya event during the six-month interval) had an upper magnitude limit of 2.6. The actual event magnitude, according to Carter et al (1993) was 2.5.

This event was detected by ARCESS (P and S), Spitsbergen (P and S), NORESS (P) and Apatity (S). In addition, the Kola Science Centre provided readings for the station Amderma (Pg and Sn) made from analog recordings. Tables 7.4.1 and 7.4.2 summarize the available observations for this event. Table 7.4.3 gives the results of applying the LOCSAT program (Bratt and Bache, 1988) to this parameter set.

Our results indicate that the epicenter was slightly to the north of the test site. However, there are some uncertainties in the travel time tables, and an on-site location cannot entirely be ruled out. We are hesitant to introduce travel-time corrections in this case, since no good reference event is available for some of the key stations.

A plot of the IMS-processed traces is shown in Fig. 7.4.7. Notice in particular the high SNR at the Spitsbergen B2 single sensor (filter band 8-16 Hz) and on the ARCESS array beam. Fig. 7.4.8 shows the IMS solution for this event. The Amderma station is not included in the IMS processing, but adding its data does not cause any significant change in the event location.

Conclusions

This work has documented the practical capability of the Continuous Seismic Threshold Monitoring method to monitor a specific nuclear test site at a very low threshold over an extended time period.

Specifically, we have used the Fennoscandian array network (NORESS, ARCESS and FINESA) to monitor the northern Novaya Zemlya test site for a full four-month period at a threshold of $m_b = 2.75$. We have identified only one instance where an event close to this threshold has occurred near the test site. In fact, the event magnitude (2.5) was below our target threshold, but the peak was still easily identified on the threshold trace.

Recently, additional array stations have been installed or are planned for installation in the Arctic region. These stations would contribute to further improving the CSTM capability, both for Novaya Zemlya and on a general regional basis. This will be the subject for additional studies in the future.

T. Kværna
F. Ringdal

References

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Station	Lat (°N)	Lon (°E)	Type of Station
AMD (Amderma)	69.742	61.655	3-comp analog
APA (Apatity)	67.600	33.000	Array
ARA0 (ARCESS)	69.535	25.506	Array
FIA0 (FINESA)	61.444	26.079	Array
NRA0 (NORESS)	60.735	11.541	Array
SVA (Spitsbergen)	78.180	16.350	Array

Table 7.4.1. Location of stations used in this study.

Station	Phase	Type[1)]	Arrival time	Azimuth	St. dev.[2)]
AMD	Pg	t	09.30.43.7	-	2.0
AMD	Sn	t	09.31.20.7	-	2.0
APA	Sn	t	09.33.22.0	-	2.0
ARC	Pn	t	09.31.48.7	-	1.0
ARC	Pn	a	-	62.5	15.0
ARC	Sn	t	09.33.37.2	-	2.0
ARC	Sn	a	-	58.4	15.0
NRS	P	t	09.34.04.3	-	1.0
NRS	P	a	-	24.0	15.0
SVA	Pn	t	09.31.50.7	-	1.0
SVA	Sn	t	09.33.41.7	-	2.0

Table 7.4.2. Observed arrivals for the 31 Dec 92 event.

1) t = time, a = azimuth

2) A priori standard deviation in seconds (time) or degrees (azimuth)

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Final location estimate (+/- S.D.):
     Latitude:   73.620 deg. +/-     6.673 km.
    Longitude:   55.196 deg. +/-     7.177 km.
        Depth:    0.000  km. +/-     0.000 km. (Fixed)
Relative O.T.:  -79.301 sec. +/-     0.849 sec.
Absolute O.T.:  -79.301 sec. +/-     0.849 sec.
             : 1969 12 31 23:58:40.70

Confidence region at 0.90 level:
  Semi-major axis:     18.1  km. =  0.16 deg.
  Semi-minor axis:     10.6  km. =  0.10 deg.
Major-axis strike:     49.3 deg. clockwise from North
 Orig. time error:      1.4 sec.

Standard errors (sigma):
             Prior:  1.00 (  9999 deg. of freedom)
         Posterior:  1.00 ( 10007 deg. of freedom)
         Posterior:  0.65 (Normalized sample S.D.)

     Azimuthal weighting:  1.00
Effective rank of matrix:  2.00
   Maximum azimuthal GAP:  195 deg.
 - No damping required !
```

Ariv ID	Statn	Phase	Data Type	at	Residuals True	Residuals Normalized	Distance (deg.)	Azimuth (deg.)	Data Import	Err
245771	APA	Sn	t	d	-0.087	-0.044	9.417	241.62	0.314	0
245771	AMD	Pg	t	d	0.900	0.450	4.371	149.27	0.319	0
245771	AMD	Sn	t	d	-1.495	-0.748	4.371	149.27	0.455	0
245782	NRS	P	t	d	1.068	1.068	20.495	254.54	0.016	0
245782	NRS	P	a	d	-9.782	-0.652	20.495	254.54	0.000	0
245782	ARC	Pn	t	d	-0.317	-0.317	10.096	261.08	0.055	0
245782	ARC	Pn	a	d	9.672	0.645	10.096	261.08	0.000	0
245782	ARC	Sn	t	d	-1.009	-0.504	10.096	261.08	0.220	0
245782	ARC	Sn	a	d	5.572	0.371	10.096	261.08	0.000	0
245782	SVA	Pn	t	d	-0.320	-0.320	10.244	313.75	0.408	0
245782	SVA	Sn	t	d	-0.033	-0.016	10.244	313.75	0.211	0

Table 7.4.3. Epicenter solution for the 31 Dec 92 event at Novaya Zemlya using the LOCSAT program (Bratt and Bache, 1988). The depth has been constrained to 0. See Table 7.4.1 for station locations and Table 7.4.2 for observed arrival data and assumed a priori standard deviations.

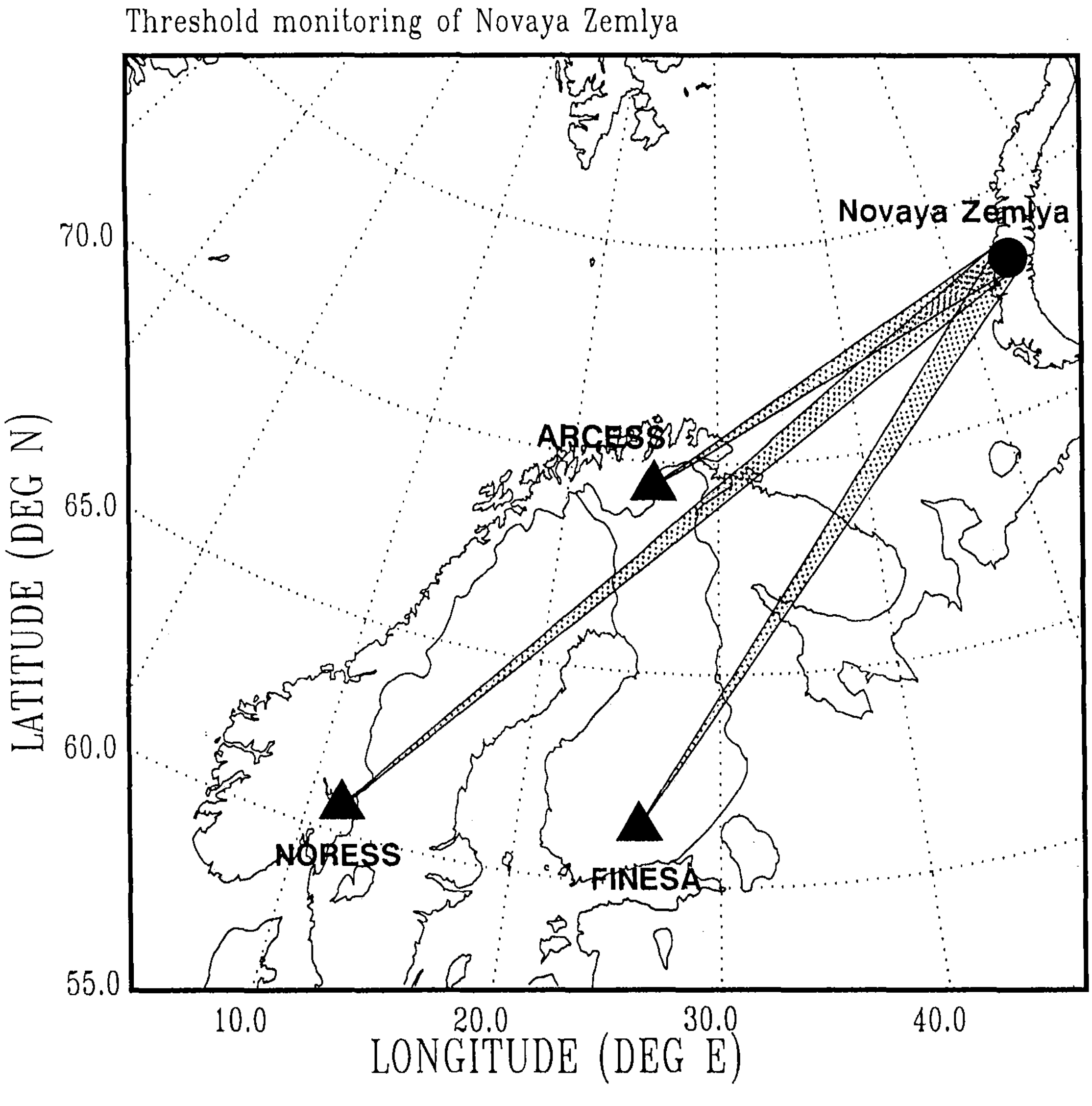

Fig. 7.4.1. Location of the target area (the northern Novaya Zemlya test site) for the monitoring experiment. The locations of the three arrays NORESS ($\Delta = 2280$ km), ARCESS ($\Delta = 1100$ km) and FINESA ($\Delta = 1780$ km) are indicated.

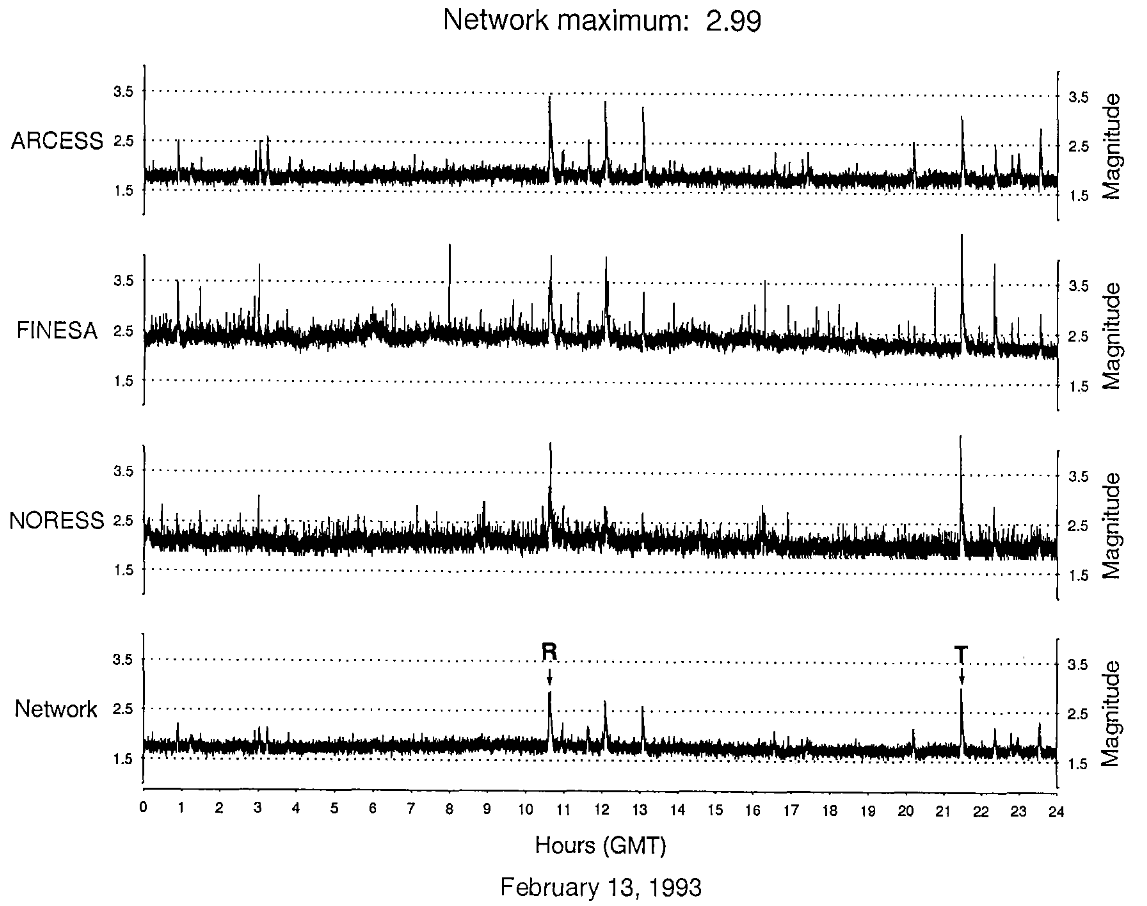

Fig. 7.4.2. Example of continuous threshold monitoring of Novaya Zemlya for one day (13 February 1993). A "threshold trace" is shown for each of the 3 arrays, and the combined network threshold trace is shown at the bottom. Note that the network threshold is well below magnitude 2.5 almost all the time.

Threshold Monitoring - Novaya Zemlya

Date: February 13, 1993 **Day_of_year:** 1993-044

	# peaks	# seconds	% of time
Mag >2.50	4	335	0.39
Mag >2.75	2	67	0.078
Mag >3.00	0	0	0
Mag >3.50	0	0	0

Individual Peaks > 2.75

TM_{max}	TM_{time}	# sec > 2.75	Reg Tele	Or.time	Lat	Lon	Depth	Mag	Agency	Explanation
2.89	10.38.10	27	R	10.37.16	68.1N	32.9E	0	2.4	IMS	Kola Peninsula, Russia, probable explosion
2.99	21.26.57	40	T	21.19.35	51.1N	176.4E	33F	5.4	IMS	Rat Islands, Aleutian Islands, earthquake

Fig. 7.4.3. Characterization of individual peaks in the threshold plot for 13 February 1993 (Fig. 7.4.2). The two peaks exceeding m_b = 2.75 are due to an event in the Kola Peninsula and an earthquake in the Aleutian Islands.

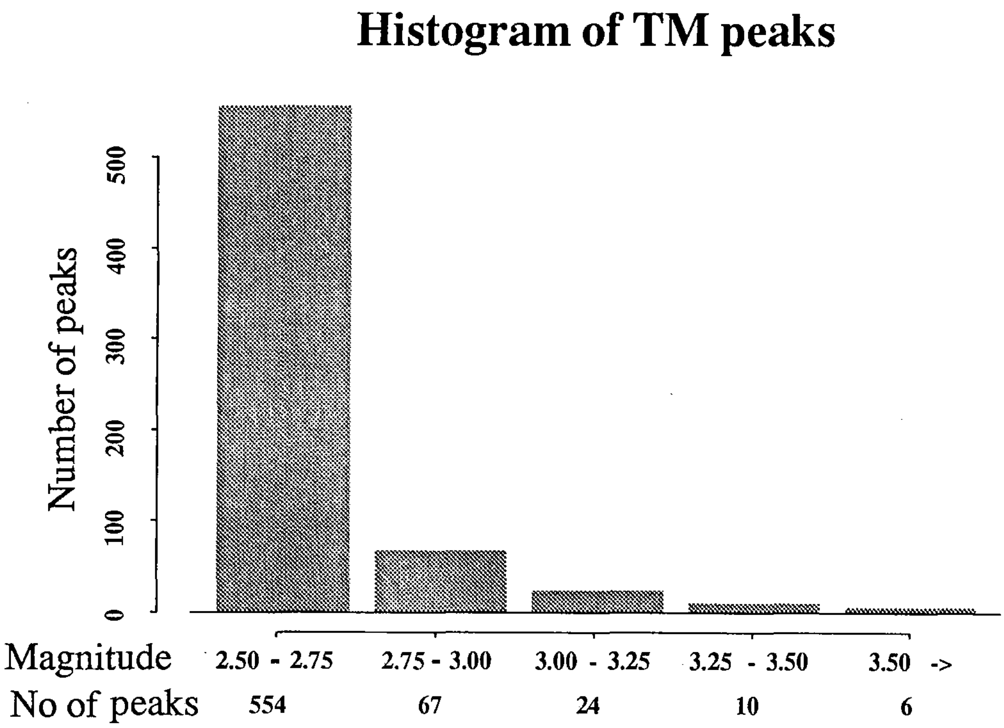

Fig. 7.4.4. Histogram showing the distribution of peaks on the network threshold trace for the four-month monitoring experiment.

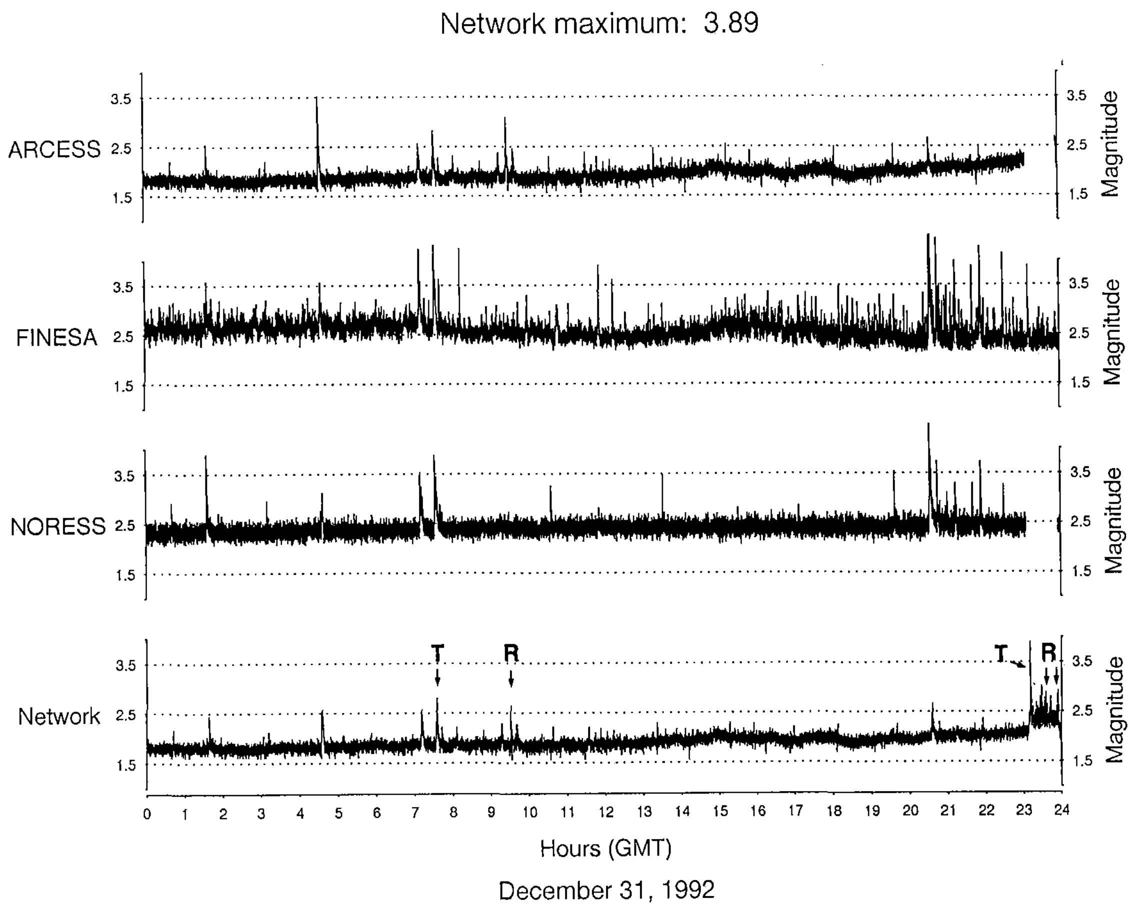

Fig. 7.4.5. Threshold plot for 31 Dec 92 (see Fig. 7.4.3 for explanation). The small Novaya Zemlya event at 09.29 GMT is indicated.

Threshold Monitoring - Novaya Zemlya

Date: December 31, 1992 **Day_of_year:** 1992-366

	# peaks	# seconds	% of time
Mag >2.50	14	648	0.75
Mag >2.75	6	107	0.12
Mag >3.00	2	19	0.022
Mag >3.50	1	7	0.0081

Individual Peaks > 2.75

TM_{max}	TM_{time}	# sec > 2.75	Reg Tele	Or.time	Lat	Lon	Depth	Mag	Agency	Explanation
2.80	07.34.10	8	T	07.25.10	27.4N	138.8E	33F	4.9	IMS	Bonin Islands Region
2.64	09.29.23	0	R	09.29.24	73.6N	55.2E	0F	2.3	IMS	Novaya Zemlya
3.89	23.09.49	38	T	32.01.06	22.3N	146.9E	33F	4.7	IMS	North Pacific Ocean
3.02	23.27.45	31								Gap in ARCESS and NORESS recording. Local noise at FINESA.
2.88	23.34.38	11								Gap in ARCESS and NORESS recording. Local noise at FINESA.
2.79	23.42.23	5	R							Local event at FINESA.
2.92	23.53.35	14	R							Local event at FINESA.

Fig. 7.4.6. Threshold monitoring statistics for 31 Dec 92. Note that there were some data problems just before midnight, causing a rise in the threshold.

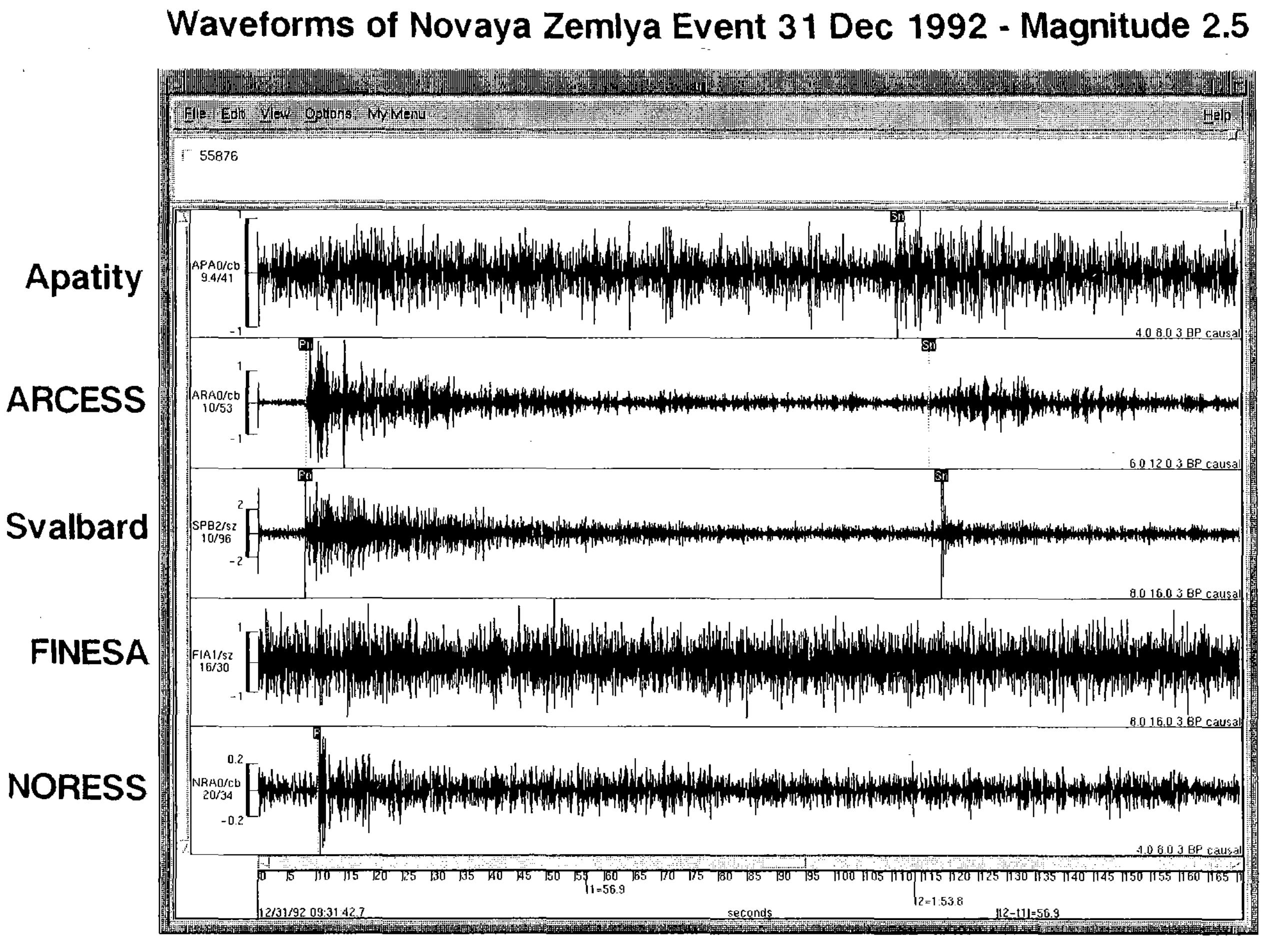

Fig. 7.4.7. Waveform plots for 5 regional arrays for the Novaya Zemlya event on 31 Dec 92. There are P-phase detections at ARCESS, Svalbard (Spitsbergen) and NORESS, and S-phase detections at Apatity, ARCESS and Svalbard.

Novaya Zemlya event 31 Dec 1992

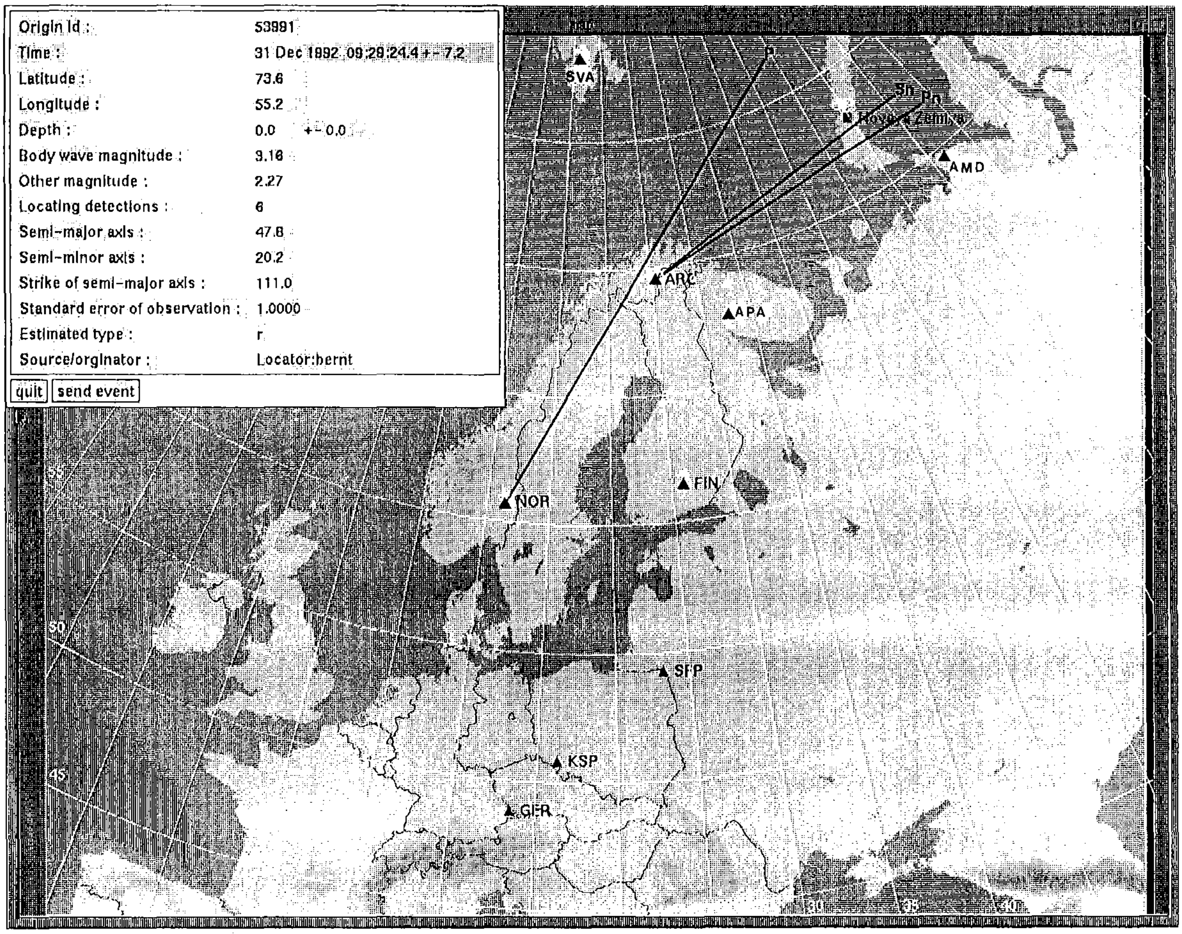

Fig. 7.4.8. IMS solution and associated error ellipse for the Novaya Zemlya event ($m_b \sim 2.5$) on 31 Dec 92.