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7.2 Optimized Threshold Monitoring

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Summary

In order to enhance the automatic monitoring capability of particularly interesting areas, we have analyzed events from the region around the Novaya Zemlya (NZ) nuclear test site to come up with a set of optimized processing parameters for the arrays SPITS, ARCES, FINES, and NORES. From analysis of the tuning events we have derived values for beamforming steering delays, filter bands, STA lengths, phase travel-times, and amplitude-magnitude relationships for each array. By using these parameters for Threshold Monitoring (TM) of the NZ testing area, we obtain a monitoring capability varying between m_b 2.0 and 2.5 during normal noise conditions. The advantage of using a network, rather than a single station or array, for monitoring purposes becomes particularly evident during intervals with high global seismic activity (aftershock sequences), high seismic noise levels (wind, water waves, ice cracks) or station outages. For the time period November-December 1997, all time intervals with network magnitude thresholds exceeding m_b 2.5 were manually analyzed, and we found that all these threshold peaks could be explained by teleseismic, regional, or local signals from events outside the NZ testing area. We could therefore conclude at the 90% confidence level that no seismic event of magnitude exceeding 2.5 occurred at the Novaya Zemlya test site during this two-month time interval.

To obtain a fully automatic monitoring procedure, we have started to investigate the possibility of utilizing detector information for labelling the threshold peaks. Results so far indicate that the azimuth and slowness estimates of the detected phases at the individual arrays can be effectively used for such labelling. It is, however, important to identify azimuth and slowness estimates that are likely to be incorrect, *e.g.*, by introducing additional quality criteria.

Objective

The objective of this work has been to improve the Threshold Monitoring (TM) algorithm for use in monitoring compliance with the Comprehensive Test Ban Treaty. In particular, we have investigated improvements associated with the use of station-specific travel-time and slowness/azimuth corrections, optimized bandpass filters for sites to be monitored, and integration of results with traditional detectors.

Research accomplished

Experimental Threshold Monitoring of the Novaya Zemlya (NZ) Test Site

We have improved the monitoring capability of the NZ Test Site by deriving optimized processing parameters for the SPITS array (see Fig. 7.2.1). At ARCES, FINES, and NORES, the processing parameters have previously been derived from recordings of underground nuclear explosions at the test site, but at SPITS no such recordings are available. For the SPITS array we have analyzed recordings of other events located in the vicinity of the island of Novaya Zemlya to come up with estimates of the processing parameters to be used for the actual test site. Key events in this analysis have been the m_b 3.5 event of June 13, 1995, located about 200 km north of the test site, and the two events (m_b 3.5 and 2.6) of August 16, 1997 located in the Kara Sea about 140 km south-east of the test site. A summary of the processing parameters for the four arrays is given in Table 7.2.1.

In order to investigate the utility of the TM method in an operational environment, we have implemented continuous calculation of the threshold level for the NZ test site using the four arrays shown in Fig. 7.2.1. Plots are generated for each day processed, and currently we have results available for 8 months since November 1, 1997. Figs. 7.2.2 and 7.2.3 show results from the monitoring study, and we now have such figures available for 6 months since November 1, 1997. In each figure, the network trace (*i.e.*, the combined threshold trace, using P-phases for all arrays and S-phases for ARCES and SPITS) is shown on the top. The traces for each of the four stations (P-phases only) are shown below the network trace.

Table 7.2.1. TM processing parameters for the NZ Test Site

Station	Dis-tance (km)	Phase	Obs. slowness (s/deg)	Obs. back azimuth (s/deg)	Frequen-cy band (Hz)	STA lengt h	Trav-el time	Mag. cal-ib.	St. dev of cal-ib.
ARCES	1108.6	P	11.2	62.2	3.0 - 5.0	5.0	147.5	2.84	0.3
-	-	S	23.2	64.3	3.0 - 5.0	3.0	254.2	2.99	0.3
SPITS	1154.2	P	14.8	109.6	3.0 - 5.0	5.0	152.6	2.95	0.3
-	-	S	23.0	97.6	3.0 - 5.0	3.0	263.0	3.11	0.4
FINES	1776.9	P	11.6	29.6	2.0 - 4.0	1.0	224.2	2.78	0.3
NORES	2267.3	P	10.9	33.6	1.5 - 3.5	1.0	281.4	2.68	0.3

The first part of Fig. 7.2.2 (5 December 1997) shows thresholds during typical "quiet" conditions where the upper magnitude thresholds for possible events at the NZ test site fluctuate around m_b 2.0. Around noon that day, a large (M_S 7.7) earthquake occurred near the E. coast of Kamchatka, followed by a very large aftershock sequence. We note that the individual arrays have large numbers of peaks corresponding to these aftershocks, whereas the network threshold trace is much less influenced by the aftershock sequence, ensuring a monitoring capability below m_b 2.5 for almost the entire time period. However, we should add that the situation would have been quite different if the sequence has taken place near the target area for the monitoring.

Fig. 7.2.3 shows a second example, which covers 16 December 1997. Two important features are illustrated in this figure. First, the key array SPITS happened to be out of operation, resulting in a general deterioration of the combined network capability. Second, there was an unusually large increase in the background noise level at the other key array, ARCES. This increase was caused by a very strong storm system moving through northern Norway at that time, producing increased microseismic noise at ARCES over the entire frequency spectrum. In spite of the coincidence of these two unfavorable factors, we note that the network threshold trace still, in general, remains below magnitude 2.5. There are about 10 peaks slightly exceeding 2.5 this day, but they can all be "explained" as resulting from interfering events.

During November and December, 1997, we found 90 peaks on the network threshold trace that exceeded m_b 2.5, of which 73 were caused by teleseismic earthquakes, and in particular the

Kamchatka aftershock sequence. The remaining 17 peaks were correlated with small earthquakes close to SPITS and some local events in Fennoscandia (mostly mining explosions).

During these two months, the continuous TM method was able to provide results that enabled monitoring of the NZ test site down to m_b 2.0 for most of the time period. All peaks exceeding mb 2.5 were correlated to events outside the target region, so we can therefore conclude at the 90% confidence level that no seismic event of magnitude exceeding 2.5 occurred at the NZ test site during the time period November - December, 1997.

Analyzing threshold traces using detector information

In an attempt to come up with an automatic analysis procedure for the Novaya Zemlya threshold traces, we have started to investigate the possibility of utilizing detector information for labelling the threshold peaks. The idea is to associate the peaks of the threshold traces with detected signals at the different arrays, and then use the signal measurements to characterize the signals as originating from sources **outside** the NZ test region.

In this initial study, we have focused on magnitude thresholds calculated from SPITS P-phases alone, but we could as well have used the network threshold trace as the basis. An example for the one hour time interval 19:00-20:00 on March 14, 1998, is shown in Fig. 7.2.4, and we refer to the figure text for details on the content of the different panels. During this one-hour interval we have found eight threshold peaks exceeding m_b 2.5, and two of these peaks reach the 3.5 level. Except for the detections associated with peak no. 7, all azimuth and slowness estimates differ by more than 18 s/deg from the predicted horizontal slowness of NZ P-phases. For the detections associated with peak no. 5, the differences are between 5 and 10 s/deg, which also is outside our area of interest. From manual analysis of the SPITS data we found that peak no. 7 was caused by a P-phase from an m_b 5.3 event located in northern Iran. The other peaks were all caused by events within 300 km of the SPITS array.

The most important conclusion from Fig. 7.2.4 is illustrated by the shaded region on the bottom panel. We note that none of the 8 peaks have slowness/azimuths near this shaded region, which corresponds to expected values for "real" NZ events. Thus it is possible to automatically explain all of the peaks as resulting from non-NZ events.

These results, and results from analysis of other time intervals, suggest that information provided by the automatic detection analysis can be effectively used to "explain" the peaks in the threshold trace calculated from a single array. We have so far only used the azimuth and slowness estimates, but additional measurements like frequency content, polarization attributes and estimates of the signal loss can also be considered. It is well known that automatic azimuth and slowness estimation in some cases produces erroneous results. This can be due to problems like wrong positioning of the analysis window, data errors, or low SNR. In addition, the array configuration limits the resolution of the slowness estimates. It will therefore be necessary to develop quality criteria for the azimuth and slowness estimates, so that we can recognize results that have a high likelihood of being wrong.

Conclusions and recommendations

For site-specific monitoring it is important to be aware that the main purpose of the threshold monitoring method is to call attention to any time instance when a given threshold is exceeded. This will enable analysts to focus their efforts on those events that are truly of interest in a monitoring situation. Other, traditional analysis tools will then be applied for detecting, locating and characterizing the source of the disturbance. We will, however, continue to develop the tools for automatic labelling the threshold peaks using information from the signal detector. In this way we hope to reduce the number of instances where manual analysis is needed for explaining the cause of the threshold peaks.

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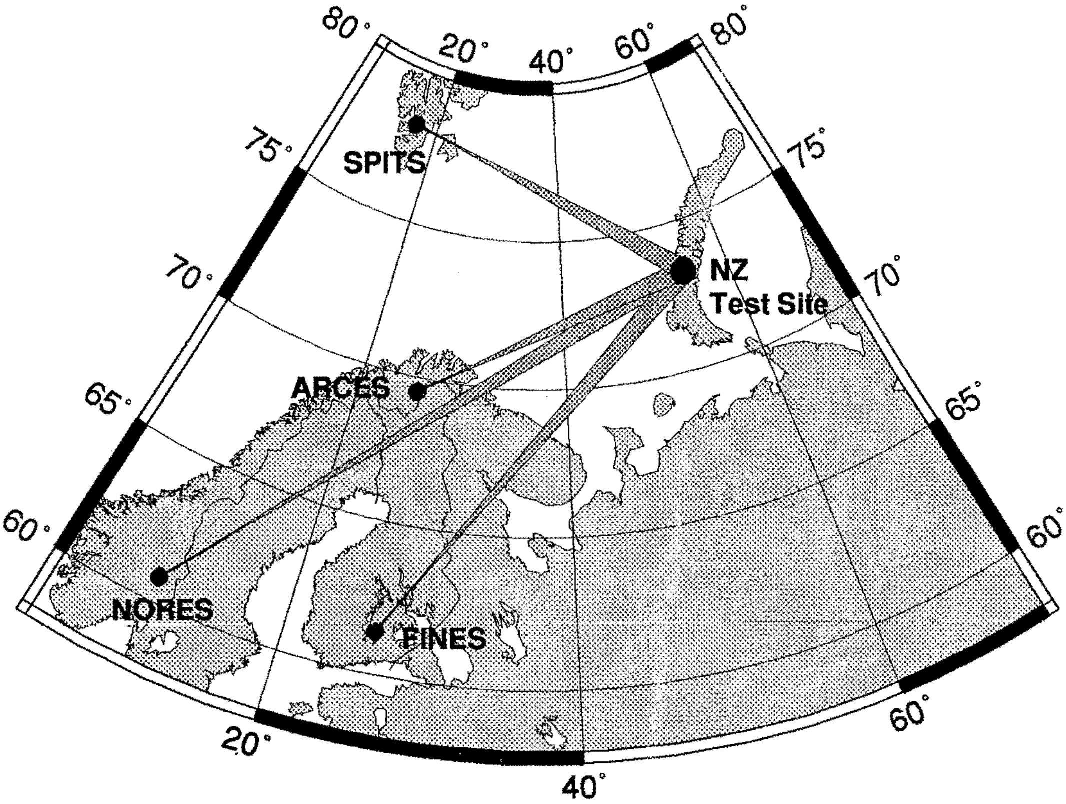

Fig. 7.2.1: Map of Novaya Zemlya and the locations of the four arrays (SPITS, ARCES, FINES, and NORES) used to monitor the region around the former underground nuclear test site.

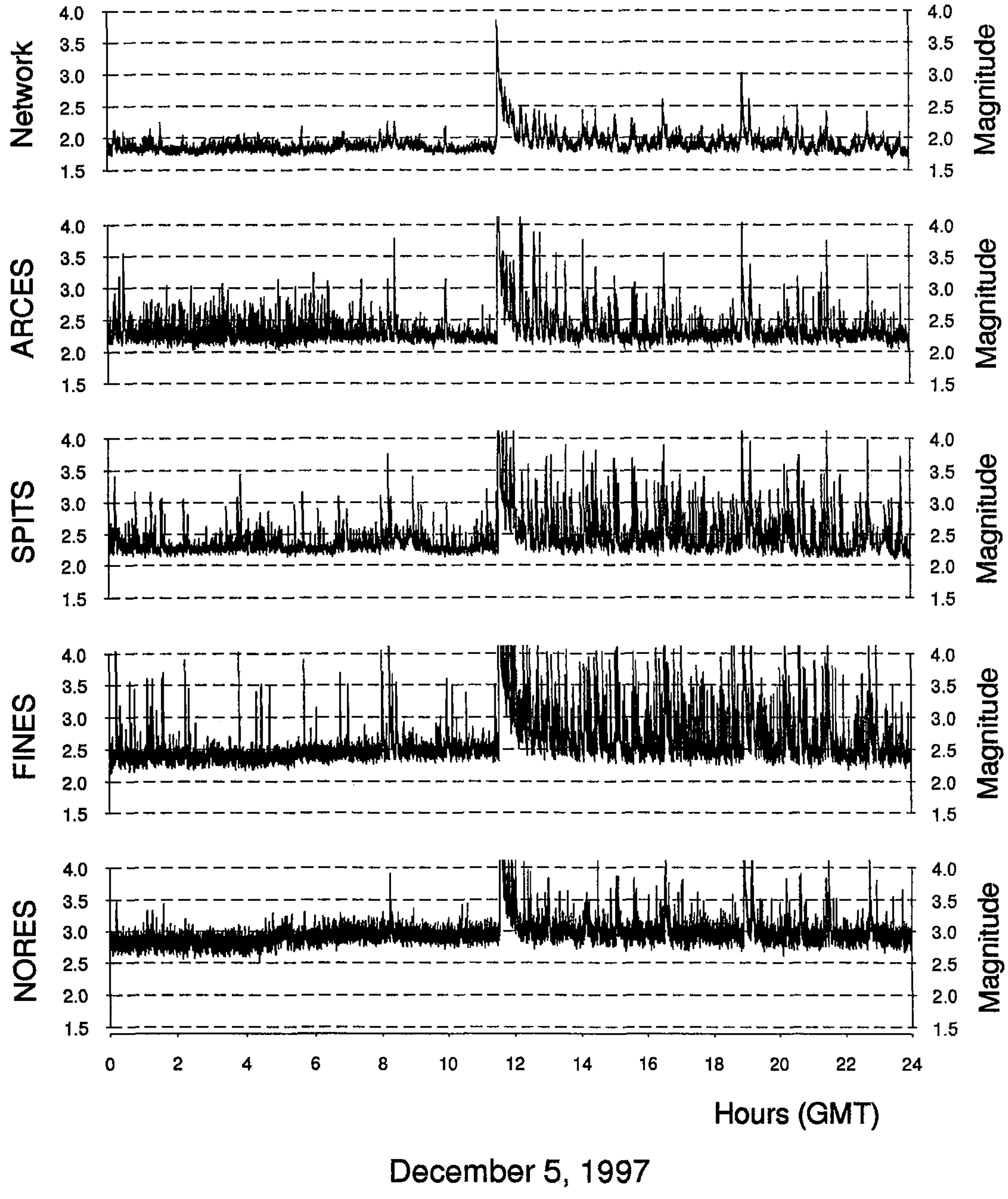

Fig. 7.2.2. Results from threshold monitoring of the Novaya Zemlya Test Site for December 5, 1997. The network trace on top is the combined threshold trace, using P phases for all arrays and in addition S phases for ARCES and SPITS. The traces for each of the four stations (P phases only) are shown below the network trace. The peaks starting around noon correspond to signals from a large (M_S 7.7) earthquake which occurred near the E. coast of Kamchatka, followed by a very large aftershock sequence. Notice that before the earthquake occurred there are no instances where the network threshold trace exceeds magnitude 2.5. Also notice that the individual arrays have large numbers of peaks corresponding to aftershocks, whereas the network threshold trace is much less influenced by the aftershock sequence.

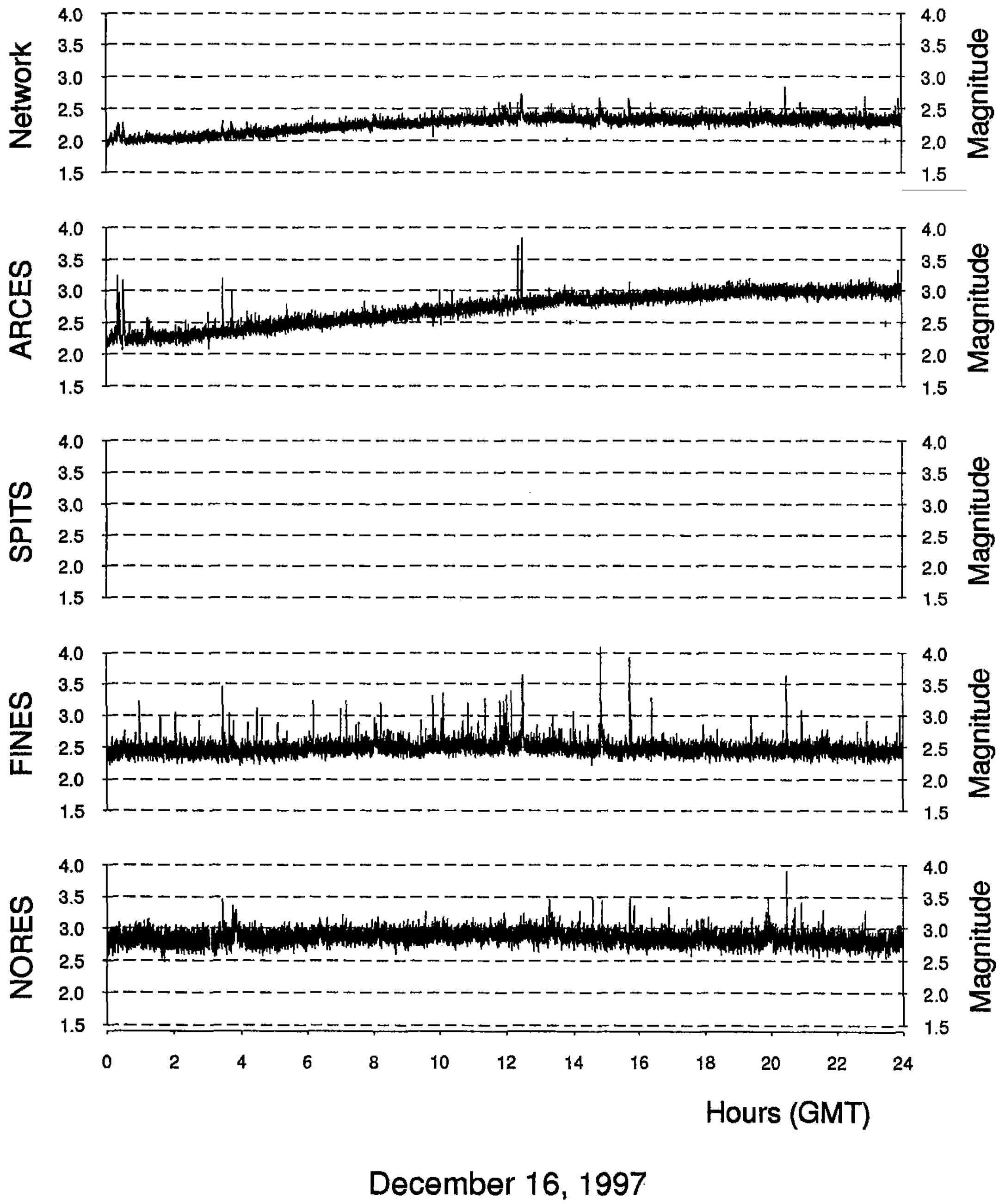

Fig. 7.2.3. Results from threshold monitoring of the Novaya Zemlya Test Site for December 16, 1997. Two important features are illustrated in this figure. First, the SPITS array happened to be out of operation, resulting in a general deterioration of the combined network capability. Second, there was an unusually large increase in the background noise level at the other key array, ARCES, caused by a very strong storm system moving through northern Norway at that time.

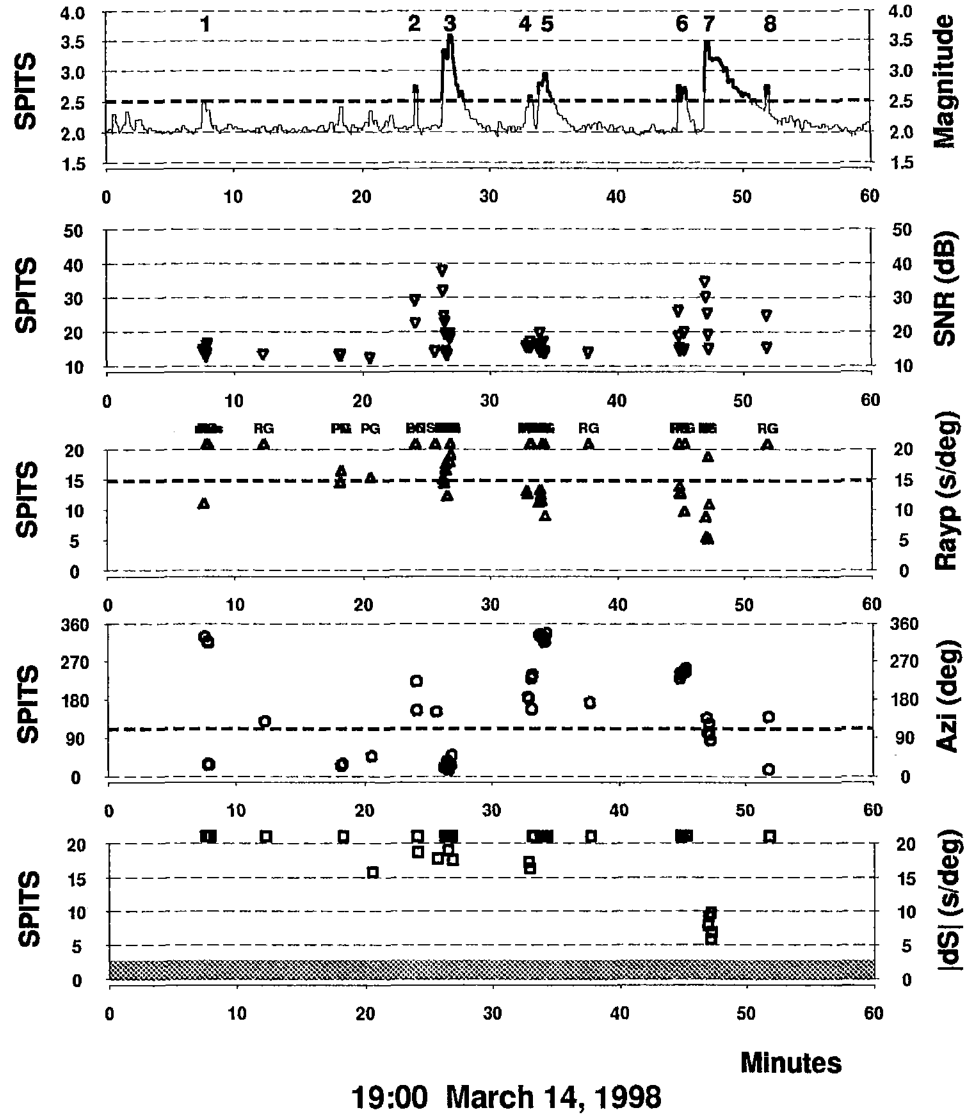

Fig. 7.2.4. Results from correlating NZ magnitude thresholds calculated from SPITS array data (P-phase only) with information from the signal detector. The upper panel shows the NZ magnitude thresholds for the one-hour interval 19:00-20:00 on March 14, 1998. Threshold peaks exceeding 2.5 are highlighted and labelled. The next four panels show different types of information from the signal detector.
Panel no. 2 shows the SNR (in dB) of the SPITS detections.
Panel no. 3 shows the estimated slownesses of the detections (in s/deg). Notice that slownesses exceeding 20 s/deg are plotted just above the 20 s/deg line. Local Rg phases at SPITS often have slownesses exceeding 70 s/deg. Phase type hypotheses based on the slowness estimates are plotted above the panel. The bold dashed line indicates the expected slowness of P-phases from events at the NZ test site (14.76 s/deg).
Panel no. 4 shows the estimated azimuths of the detections. The bold dashed line indicates the expected azimuth of P-phases from events at the NZ test site (109.6 deg).
Panel no. 5 shows the differences in horizontal slowness estimates between the detected signals and predicted P-phases from the NZ test site (in s/deg). Detections with differences exceeding 20 s/deg are plotted above the panel. The shaded region within 2.5 s/deg indicates the range of interest for NZ P-phases.