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6.3 Site-Specific Threshold Monitoring (SSTM) applied to the Lop Nor test site

Introduction

Continuous seismic threshold monitoring (TM) is a technique that has been developed at NORSAR over the past decade to monitor a geographical area continuously in time. Data from a network of arrays and single stations are combined and “steered” toward a specific area to provide a continuos assessment of the upper magnitude limit of seismic events that might have occurred in that area.The basic principles have been described by Ringdal and Kværna (1989, 1992), who showed that this method could be useful as a supplement to event detection analysis. The usefulness of the TM method for global network capability estimation has been shown by Kværna and Ringdal (1999). Examples of site-specific threshold monitoring (SSTM) applied to the former Soviet test site at Novaya Zemlya, and the Indian and Pakistani test areas have been demonstrated by Kværna et al. (2002a,b). We have also recently reported an application of this technique to the site of the “Kursk” accident in the Barents Sea.

The main purpose of the threshold monitoring technique is to highlight instances when a given threshold magnitude is exceeded, thereby helping the analyst to focus on those events truly of interest in a monitoring situation.The analyst can then apply traditional tools in detecting, locating and identifying the source of the disturbance.

In this paper we apply the SSTM technique to the Lop Nor test site in China. The emphasis will be put on detection (and location) of small seismic events with mb < 4.0, and the purpose is to evaluate the SSTM method as a potential monitoring tool. In contrast to most previous case studies, which have been based on recordings by seismic arrays at regional distances, we will in this study apply a combination of 3-component stations and arrays, at both regional and teleseismic ranges.

Our efforts so far, as reported in this contribution, comprises mainly a study of available seismic stations, selection of those stations which are most sensitive to seismic events in the Lop Nor general area, and tuning of the signal parameters of these stations so as to prepare processing recipes for the application of the threshold monitoring tool.

Development of processing recipes

For the successful implementation of SSTM, beams filtered in optimal frequency bands must be steered from the individual arrays towards the Lop Nor test site, and amplitude calibration constants developed from older events are applied to facilitate the calculation of continuous magnitude thresholds for the site. For single (or 3-component) stations, the vertical component was filtered in the optimal frequency band.

For the purposes of this study, 23 stations and arrays were initially chosen as shown in Fig. 6.3.1. For each of the stations data were collected from known nuclear tests at Lop Nor. The explosions used for the calibration is summarized in Table 6.3.1, however, for most stations only a few data sets with explosions were available for the calibration.

Event	Event	Event	Event
1990-146 M=5.5	1993-278 M=5.9	1995-135 M=6.0	1996-211 M=4.7
1992-142 M=6.5	1994-161 M=5.8	1995-229 M=5.9	
1992-269 M=5.0	1994-280 M=5.9	1996-160 M=5.8	

Table 6.3.1. Lop Nor nuclear test explosions used for the station calibration purpose (year, Julian day and magnitude of the explosion).

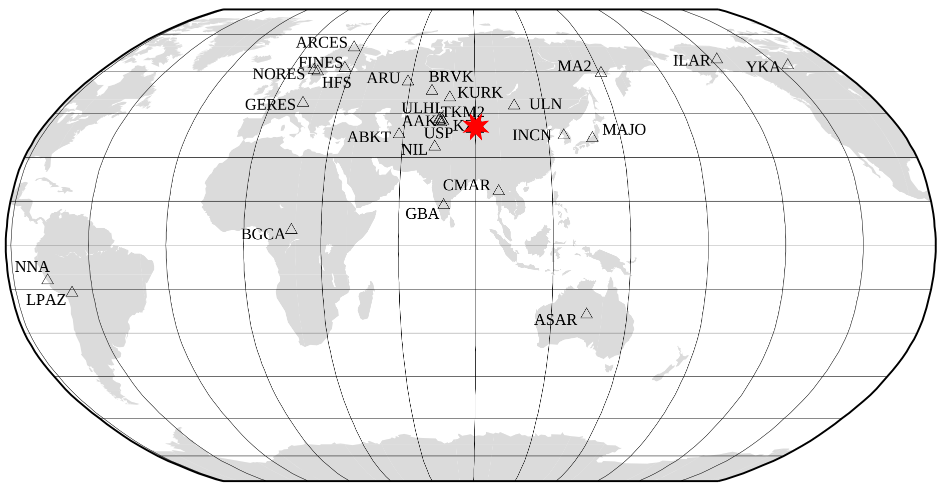

Fig. 6.3.1. Stations selected for SSTM calibration for the Lop Nor site (indicated with red star).

The calibration procedure

The development of the calibration parameters followed a 3-step procedure for the arrays listed in Table 6.3.2:

- Firstly the average azimuth and apparent velocity was obtained for the arrays. Generally, a higher power in the FK domain indicated also appropriate frequency bands.
- Through beamforming, the STA trace aimed at Lop Nor was computed for different frequency bands, and the optimal frequency band was defined based on maximum SNR.
- For the optimal beamforming parameters, the maximum corrected STA amplitude for the phase was computed and the corresponding magnitude corrections were computed.

The process is exemplified in Fig. 6.3.2, and shows the distribution of FK power with azimuth and apparent velocity in different frequency bands for the array CMAR. The final parameters extracted (and later applied in the beamsteering) from the data are apparent velocity and azimuth (for arrays), optimal frequency filtering band, phase travel time, phase amplitude and tolerance bands for these parameters. Table 6.3.2 summarizes some of the parameters obtained for the different stations and arrays.

Station	No. of records	Delta	P-travel-time	Calib. con-stant	Calib. St. devi-ation	Optimal Fre-quency Band	
AAK	7	10.48	155.6	3.32607	0.122042	1.5	4.0
ABKT	7	23.58	317.9	3.20032	0.131820	0.5	2.0
ARCES	7	42.47	478.2	3.80806	0.065702	2.0	6.0
ARU	6	24.43	322.8	3.27962	0.210574	0.5	2.0
ASAR	6	77.16	719.2	4.23516	0.209677	1.5	4.0
BGCA	1	71.7	687.2	2.24374	-	1.0	4.0
BRVK	4	16.87	239.6	3.35027	0.112567	1.0	4.0
CMAR	5	24.64	326.8	3.62734	0.298740	2.0	4.0
FINES	6	41.75	472.4	4.02934	0.208297	1.0	4.0
GBA	7	29.60	371.6	4.25127	0.178033	1.0	4.0
GERES	10	51.41	548.6	4.42041	0.241027	2.0	4.0
HFS	3	47.93	521.0	3.35685	0.063838	1.0	4.0
ILAR	8	65.57	645.9	3.69785	0.112615	0.5	2.0
INCN	1	29.5	307.7	1.80385	-	2.0	4.0
KURK	1	11.47	165.7	3.19758	-	1.0	4.0
KZA	2	9.92	149.8	1.92404	0.102790	2.0	4.0
LPAZ	5	147.8	1190.8	2.83462	0.050651	1.5	4.0
MA2	3	41.7	467.9	2.45095	0.991537	1.5	4.0
MAJO	2	38.50	443.3	2.37779	0.058921	2.0	4.0
NIL	4	14.38	209.0	2.42098	0.067611	1.0	4.0
NNA	6	147.9	1189.8	3.70520	0.108466	0.5	2.0
NORES	9	48.84	528.5	3.50340	0.245675	1.0	4.0
TKM2	1	9.68	146.0	1.96420	-	0.5	2.0
ULHL	2	9.18	139.8	1.87506	0.082691	1.0	4.0
ULN	1	14.64	216.4	1.60884	-	0.5	2.0
USP	3	10.51	156.6	2.44410	0.189674	1.0	4.0
YKA	1	74.6	702.4	4.77741	-	2.0	6.0

Table 6.3.2. The stations calibrated for the ACD Lop Nor experiment with main calibration values. For the shaded stations calibration parameters were developed, but these have not yet been implemented.

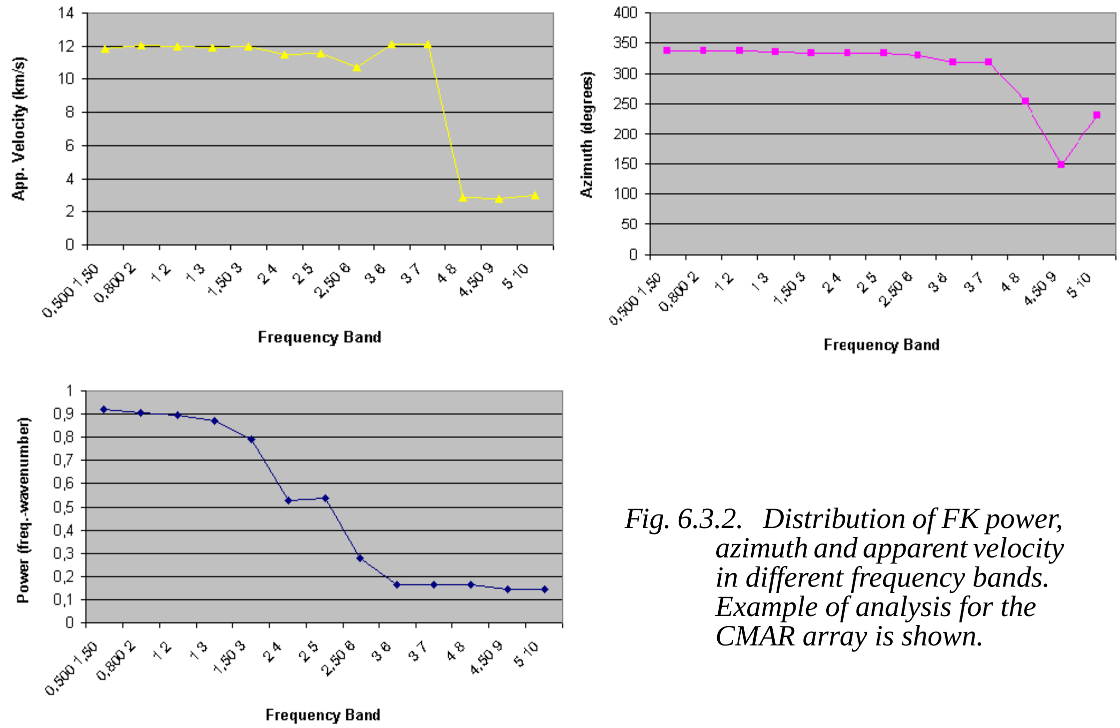

Fig. 6.3.2. Distribution of FK power, azimuth and apparent velocity in different frequency bands. Example of analysis for the CMAR array is shown.

Preliminary Results

Two performance tests were carried out. First, data for one day (September 10, 2001) was collected, and in these data the recordings of 4 explosions were scaled and embedded at some (but not all of) the stations (see Table 6.3.3). Secondly, a 10 day test period with data from August 2 through 11, 2001 was selected and data were collected for the stations. Fig. 6.3.3 shows examples of network results of these two performance tests.

Event	Time used	Scaling magn.	Stations *without* embedded, scaled data
1995/05/15	09/10/2001 05:01:19	mb 3.0	
1995/05/15	09/10/2001 09:15:13	mb 3.5	
1996/07/29	09/10/2001 06:37:43	mb 3.5	ULN, KURK
1996/07/29	09/10/2001 12:17:14	mb 3.0	ULN, KURK
1999/01/27	09/10/2001 13:25:08	mb 3.5	FINES, GERES, HFS, NORES, ULHL
1999/01/30	09/10/2001 14:23:03	mb 3.5	FINES, GERES, HFS, NORES, ULHL
1999/01/27	09/10/2001 16:59:57	mb 3.0	FINES, GERES, HFS, NORES, ULHL
1999/01/30	09/10/2001 20:59:58	mb 3.0	FINES, GERES, HFS, NORES, ULHL

Table 6.3.3. The four events/explosions scaled and embedded as eight events in the data for day 253 as shown in Figs. 6.3.3-6.3.6.

Figs. 6.3.4 and 6.3.5 shows the SSTM threshold traces for single stations and arrays respectively. In both figures, the data cover the one day (10 September 2001) which contained the scaled, embedded events, and the combined network trace (using all stations) is shown on top of each figure. It can be observed that the arrays generally have thresholds between magnitude 3.2 and 3.8, and that the network threshold is close to or better than 3.0 (based on both arrays and single stations). Some stations feature frequent data problems.

Fig. 6.3.6 shows a close-up figure of the detection parameters at ARCES for an hour where there is also an embedded event (13:25). It should be observed that the slowness and azimuth observed from the event are within the bands that are indicative for an event from the Lop Nor area (yellow shaded area).

From these tests the following preliminary observations can be stated:

- Out of the eight embedded explosions on day 253 six were flagged, and the two non-flagged could be clearly seen in the data.
- The quiet day (214) did not have any events flagged.
- On day 217 the SSTM method triggered on two large teleseismic events.
- In a monitoring situation, all peaks exceeding the threshold could be analyzed. The maximum number of such peaks during one day was 10-15 for the days processed. If such peaks were analyzed, all of the scaled events on day 2001-253 would have been found.

The above observations should be evaluated under the perspective that the calibration is a preliminary one, where the majority of the stations could only be calibrated with one or two events/explosions, and where only some of the calibrated stations were included in the performance test. Furthermore, the day with embedded events did not include embedded data for all the stations (see Table 6.3.3), and this did introduce a bias in the threshold monitoring results.

Conclusions

From the above we conclude that the Site-Specific Threshold Monitoring performance tests for the Lop Nor test site were successful. It is expected that these initial tests will be followed by more detailed studies, where in particular the calibration parameters will be more firmly established.

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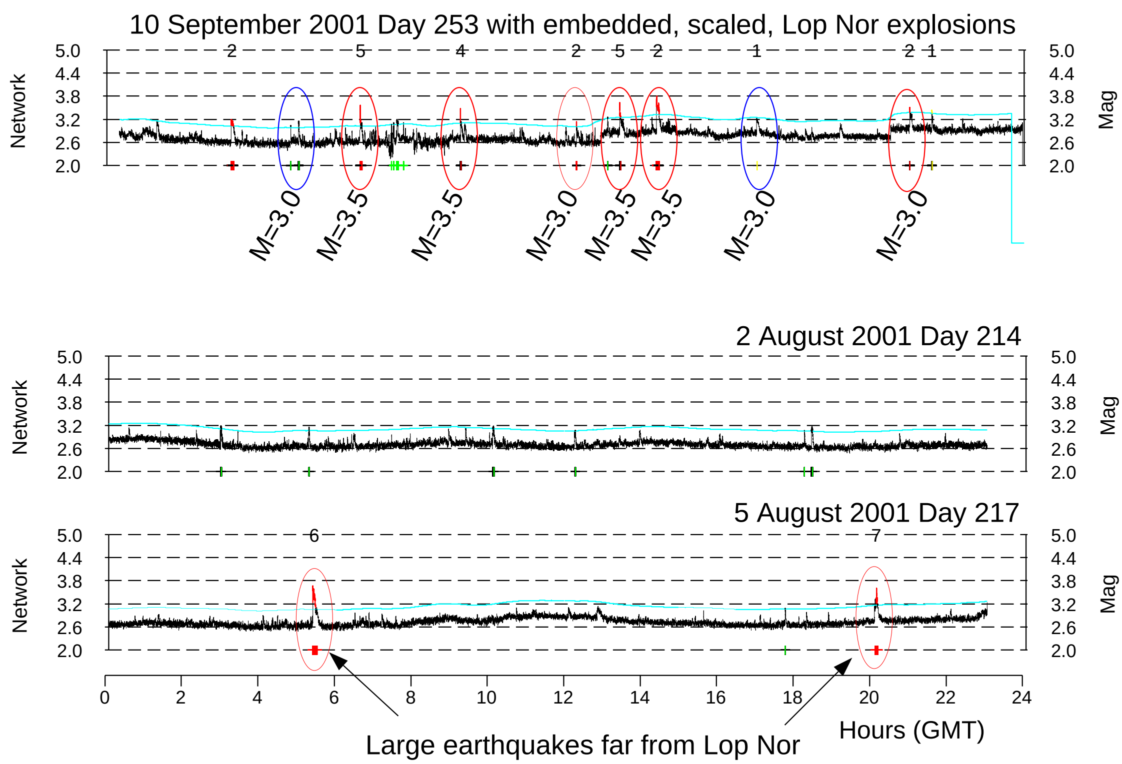

Fig. 6.3.3. The network traces from three different days. Upper trace from day 253 with embedded Lop Nor event recordings scaled to magnitudes 3.0 and 3.5. Red circles indicate that the SSTM analysis picked the events, while blue circles indicate that the events were not picked. Lower traces are from days 214 and 217. Day 214 is silent with no detections, while 217 show two detections from large earthquakes (teleseismic events far from Lop Nor).

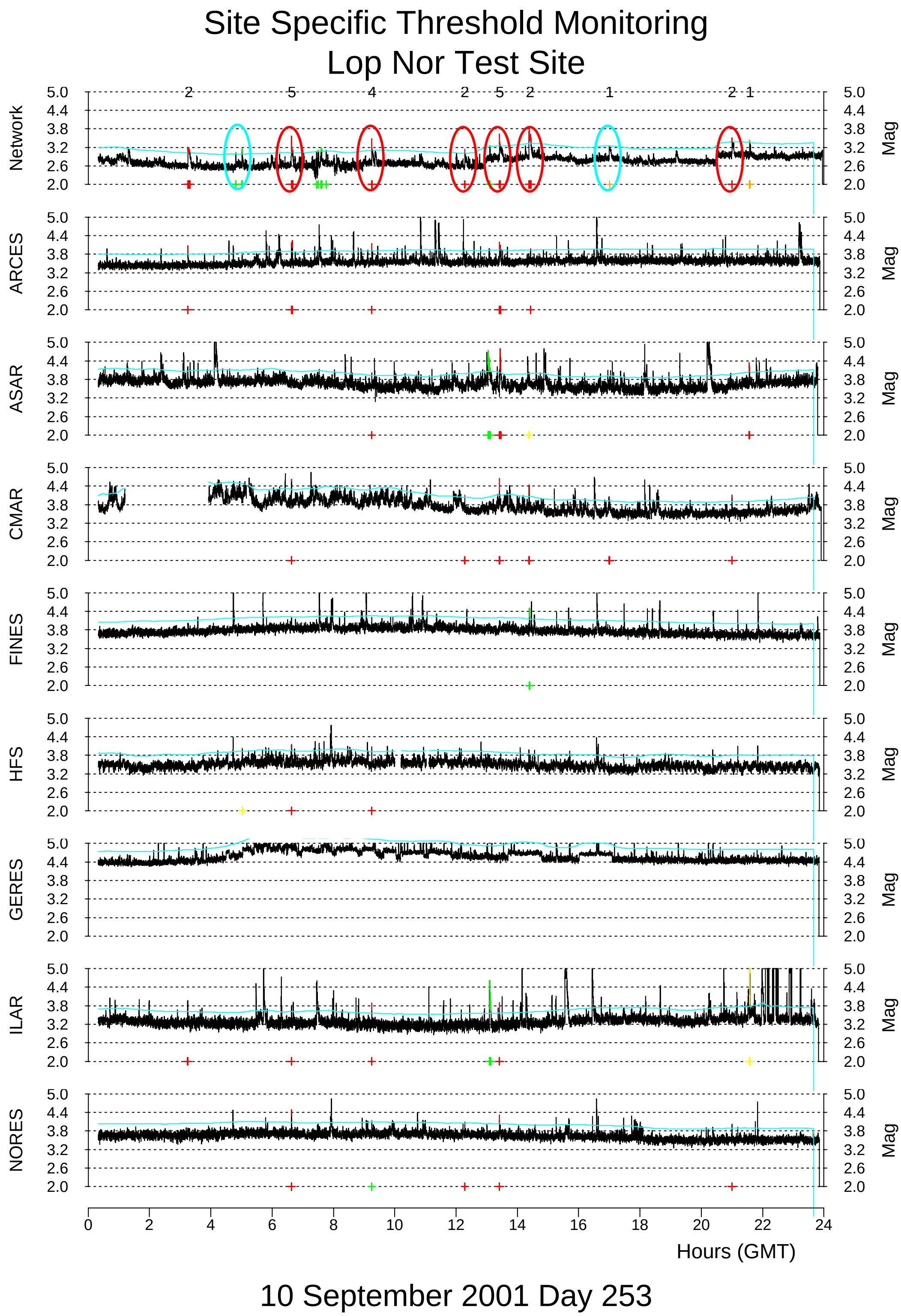

Fig. 6.3.4. Network and array TM traces for one day with embedded, scaled, events. Red circles indicate that the explosions were picked by SSTM, blue circles indicate that they were not picked.

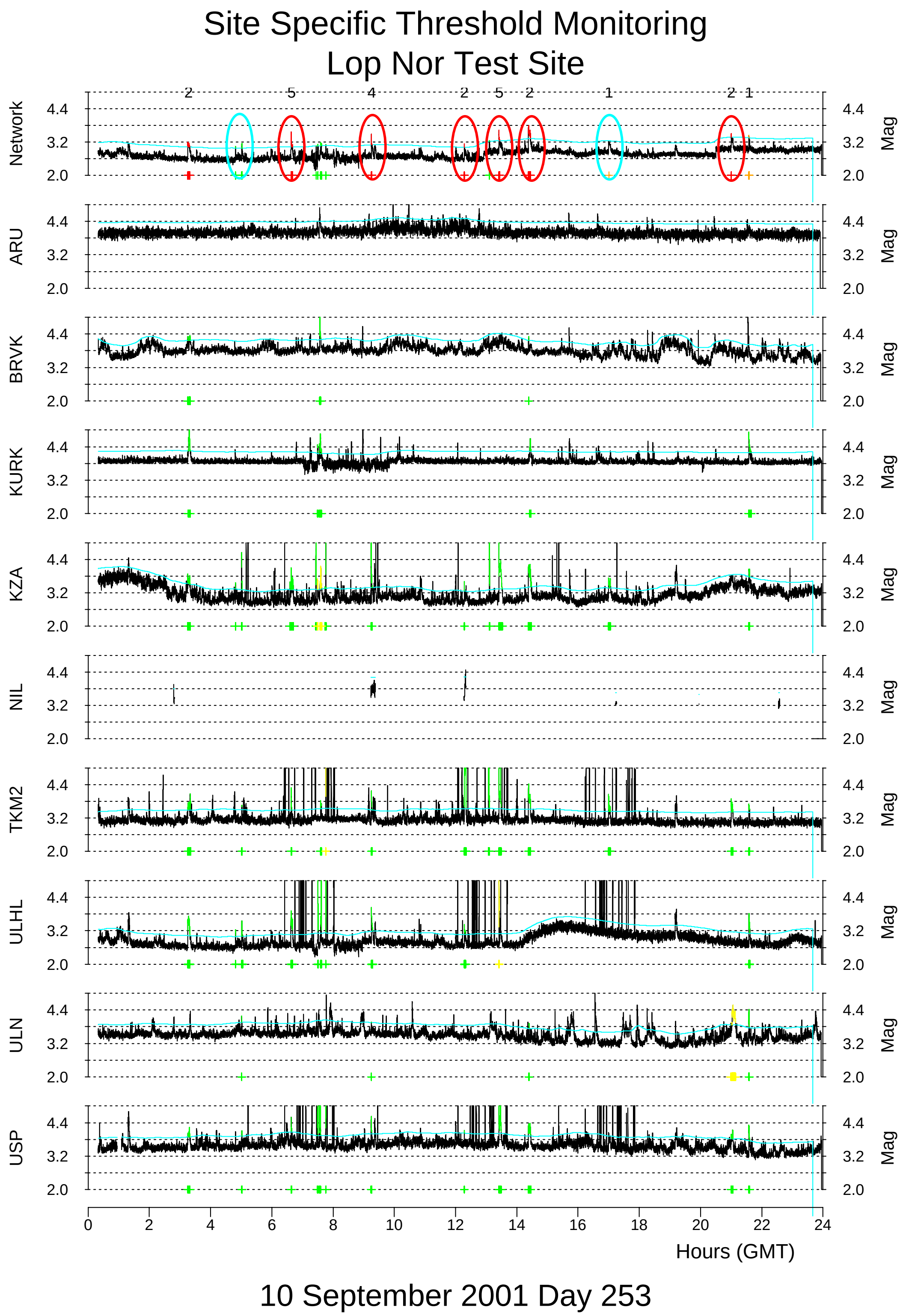

Fig. 6.3.5. Network and single station TM traces for one day with embedded, scaled, events. Red circles indicate that the explosions were picked by SSTM, blue circles indicate that they were not picked.

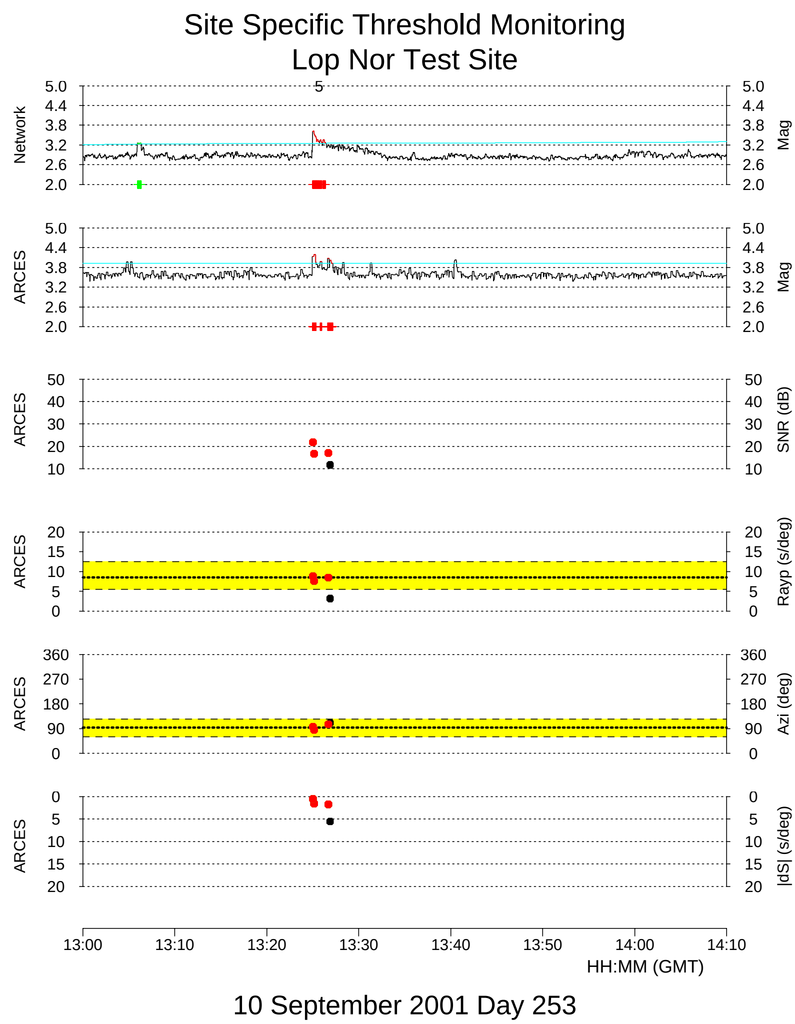

Fig. 6.3.6. Network and ARCES TM traces for one day and one hour with one embedded, scaled, event. The lower traces provide additional information for the ARCES station. The yellow shaded areas indicate the azimuth and slowness bands expected from a Lop Nor event.