NORSAR

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6.3 Threshold Monitoring processing parameters for IMS stations BRAR and NVAR

Introduction

The processing parameters for all stations to be included in the IMS Threshold Monitoring System processing need to be tuned for reliable estimation of the detection capability. We will now report on the tuning of the IMS array stations BRAR and NVAR, and we follow the procedures described in the Threshold Monitoring Operations Manual (Taylor et. al., 1998).

Event Data Bases

For the tuning study we needed to find events with good SNR's, preferably occurring at various distances from the stations. This was done by searching the PIDC data base for good SNR events at various distances, and then requesting and receiving the data intervals using the AutoDRM. In order to obtain information on the background noise field, the event data segments start one minute ahead of the P arrival, with a total length of two minutes.The lists of events for BRAR and NVAR are given in Table 6.3.1 and Table 6.3.2.

Table 6.3.1. BRAR events used for TM tuning

STA	ORID	LAT	LON	DEPTH	UTM	MB	DELTA	PHASE	SNR	AZIMUTH	VEL
BRAR	20150736	40.8764	32.7625	0.0	1998-309:13.46.47.0	3.9	1.022	Pg	62.15	344.02	4.493
BRAR	20324105	38.4696	30.7440	22.5	1999-036:14.01.53.6	3.4	2.090	Pn	38.39	254.61	6.370
BRAR	20115701	39.9046	29.3379	0.0	1998-276:22.51.48.3	3.5	2.634	Pn	19.81	272.40	8.285
BRAR	19985229	36.5639	34.4738	0.0	1998-178:20.50.19.4	4.1	3.551	Pg	77.23	145.66	8.490
BRAR	20442069	36.3859	28.9362	50.2	1999-106:13.52.47.9	3.8	4.591	P	46.78	254.31	7.210
BRAR	20361880	37.2925	27.0861	0.0	1999-062:04.28.52.0	4.1	5.129	Pn	79.71	248.44	6.037
BRAR	20383875	37.3358	25.7638	0.0	1999-077:23.24.41.0	3.5	6.029	Pn	20.99	248.02	7.130
BRAR	20029578	35.1378	25.8938	55.6	1998-206:07.00.21.9	4.0	7.206	P	33.68	257.05	6.951
BRAR	20024862	34.5114	24.6733	0.0	1998-202:15.19.30.5	4.8	8.369	Pn	52.00	256.09	7.555
BRAR	20294097	41.1047	44.0036	0.0	1999-014:22.45.15.0	4.4	8.660	Pn	24.21	70.15	7.099
BRAR	20444408	36.1483	21.7937	21.3	1999-108:05.54.58.6	4.4	9.412	Pn	44.39	252.26	6.861
BRAR	20464018	44.2509	20.2049	0.0	1999-120:03.30.38.1	4.9	10.318	Pn	37.67	300.04	9.635
BRAR	20347857	43.2158	46.8683	65.8	1999-052:18.14.39.8	4.6	11.095	P	48.91	64.88	7.503
BRAR	20086480	39.9632	15.8369	0.0	1998-252:11.27.59.2	5.3	12.999	Pn	39.32	282.18	7.459
BRAR	19939287	31.6774	50.7966	0.0	1998-166:01.14.32.9	4.7	16.738	Pn	41.06	101.47	15.315
BRAR	20099400	31.0895	51.2981	0.0	1998-264:21.35.24.2	5.0	17.425	P	36.01	105.17	11.086
BRAR	20497730	29.5261	51.9812	37.0	1999-150:00.15.40.7	4.2	18.830	P	47.91	175.68	13.544
BRAR	20041925	37.3021	57.3062	0.0	1998-216:11.41.55.5	4.9	19.345	P	65.93	75.56	9.664
BRAR	20273106	27.8310	53.5947	0.0	1998-361:04.10.37.6	4.7	20.997	P	39.35	101.80	17.463
BRAR	20294086	28.9605	56.4352	27.6	1999-014:22.12.49.8	4.7	22.287	P	41.89	112.59	18.632
BRAR	20037412	27.7382	56.5350	11.6	1998-213:23.38.30.8	4.7	23.083	P	32.19	109.11	17.797
BRAR	19932006	28.1418	58.4602	92.0	1998-161:08.30.15.7	4.7	24.211	P	22.19	118.86	33.828
BRAR	1442288	26.4803	62.1511	44.5	1998-148:20.32.48.3	4.2	27.843	P	32.08	120.54	24.258
BRAR	1449288	37.1570	70.0682	0.0	1998-150:06.22.25.7	5.5	29.184	P	43.23	80.17	17.209
BRAR	20475724	13.1123	51.0996	20.4	1999-131:17.46.19.9	4.3	31.154	P	28.83	174.45	27.664
BRAR	20071443	39.7115	77.2874	0.0	1998-239:09.03.34.0	5.2	33.949	P	59.54	60.32	21.559

Table 6.3.1. BRAR events used for TM tuning

STA	ORID	LAT	LON	DEPTH	UTM	MB	DELTA	PHASE	SNR	AZIMUTH	VEL
BRAR	20009735	47.6112	82.8839	0.0	1998-193:07.16.13.0	4.7	36.492	P	41.90	60.40	14.401
BRAR	20317144	41.6679	88.5307	24.2	1999-030:03.51.07.4	5.3	41.653	P	78.90	53.04	16.105
BRAR	20023426	30.0922	88.1782	15.5	1998-201:01.05.57.8	5.2	45.805	P	59.00	84.47	24.980
BRAR	20106764	27.6699	92.8437	18.5	1998-269:18.27.05.1	5.2	50.553	P	74.83	102.32	29.400
BRAR	20380814	.2875	-15.9980	0.0	1999-075:14.42.57.6	4.6	59.293	P	26.64	253.64	8.570
BRAR	20045432	7.3823	94.2112	23.7	1998-222:09.52.15.3	5.0	63.489	P	32.00	163.07	68.393
BRAR	20450290	-27.9021	26.6636	0.0	1999-112:22.19.38.1	5.3	67.646	P	97.50	217.30	19.799
BRAR	20020736	23.3870	120.7023	0.0	1998-198:04.51.14.0	5.2	73.899	P	88.56	63.37	33.831
BRAR	20260473	31.3683	131.3748	10.7	1998-350:00.18.42.2	5.0	76.585	P	55.90	53.43	29.598
BRAR	20127734	39.9974	143.3506	0.0	1998-286:20.41.10.1	4.7	78.423	P	57.47	24.94	29.781
BRAR	20392812	33.2443	141.4208	41.2	1999-082:04.23.36.5	4.5	81.844	P	30.92	58.95	25.541
BRAR	20072966	-.0124	125.1436	28.2	1998-240:12.40.55.9	6.0	91.842	P	64.63	74.66	35.691
BRAR	20075387	17.1042	148.1133	58.0	1998-242:01.48.13.2	5.7	97.391	P	44.57	48.70	30.704
BRAR	20289367	-5.3842	151.6759	24.9	1999-012:08.49.20.4	5.0	115.473	PKP	25.00	322.08	55.075
BRAR	20094396	-5.4521	151.6698	12.0	1998-258:08.35.44.0	5.2	115.513	PKP	21.31	37.89	45.611
BRAR	20082094	-29.4519	-71.5874	40.2	1998-246:17.38.01.9	5.8	118.596	PKP	56.62	267.35	20.377
BRAR	20232267	-7.8946	158.7221	41.2	1998-329:18.05.26.6	5.5	122.339	PKP	19.58	9.32	58.934
BRAR	20099497	-13.6857	166.6767	30.3	1998-264:12.09.41.4	5.8	131.992	PKP	35.47	42.53	34.298
BRAR	20029484	-13.7545	166.8566	43.2	1998-206:02.39.25.8	5.5	132.168	PKP	59.25	346.24	70.076
BRAR	20298247	-14.9618	-173.5653	0.0	1999-020:06.02.18.2	4.5	146.163	PKPbc	36.68	332.71	48.155
BRAR	20058843	-34.8503	-108.7204	0.0	1998-230:23.07.22.2	4.8	149.142	PKPbc	64.01	276.80	18.011
BRAR	20307295	-20.9029	-174.4590	0.0	1999-026:07.04.18.3	4.9	150.048	PKPbc	75.01	333.56	71.908

Table 6.3.2. NVAR events used for TM tuning

STA	ORID	LAT	LON	DEPTH	UTM	MB	DELTA	PHASE	SNR	AZIMUTH	VEL
NVAR	20437988	36.6291	-120.7043	0.0	1999-105:03.20.34.0	3.5	2.621	Pn	16.37	105.22	4.627
NVAR	20413291	32.7819	-116.3265	0.0	1999-097:06.26.40.6	3.5	5.861	Pg	29.72	158.25	4.871
NVAR	20359687	40.8626	-126.0324	0.0	1999-059:15.33.36.9	3.8	6.440	Pn	26.11	280.87	5.836
NVAR	20499341	41.9474	-127.0332	19.3	1999-152:08.28.05.2	4.1	7.549	Pn	31.79	281.87	6.131
NVAR	20492320	43.5800	-127.3808	0.0	1999-145:23.39.47.7	4.1	8.575	Pn	25.11	301.88	7.830
NVAR	20474682	49.5528	-125.6061	32.8	1999-128:14.25.37.8	3.4	12.292	Pn	19.42	340.80	7.705
NVAR	20378288	24.9277	-108.8827	0.0	1999-072:09.11.44.3	4.1	15.654	Pn	50.85	149.49	7.607
NVAR	20413249	24.1840	-108.4301	0.0	1999-097:05.04.02.8	3.6	16.501	Pn	21.99	323.63	4.372
NVAR	20380739	22.6290	-107.2947	54.8	1999-075:06.14.16.7	3.7	18.359	P	51.37	153.63	7.000
NVAR	20491505	19.9238	-109.2556	16.4	1999-142:02.39.27.9	3.9	20.040	P	19.14	155.98	7.398
NVAR	20407926	19.4646	-101.2925	214.5	1999-092:13.05.44.1	3.2	23.982	P	15.44	145.91	8.587
NVAR	20451887	17.3752	-100.3793	45.6	1999-115:03.08.57.8	3.7	26.191	P	43.33	145.93	8.860
NVAR	20380697	16.2277	-100.0657	0.0	1999-074:17.05.12.3	3.9	27.313	P	17.86	142.80	9.142
NVAR	20404485	15.8712	-97.2961	19.2	1999-091:23.25.17.8	4.2	29.093	P	24.01	143.20	8.376
NVAR	20466045	60.5282	-153.1291	248.5	1999-122:21.53.00.6	3.1	31.037	P	30.90	151.24	6.768
NVAR	20483555	64.6161	-157.7441	0.0	1999-137:17.32.14.1	4.2	34.917	P	31.72	330.10	12.358
NVAR	20441919	11.4904	-86.0022	0.0	1999-106:16.03.17.1	4.4	39.355	P	17.78	146.86	13.974
NVAR	20400385	51.7195	-177.3390	67.6	1999-087:22.23.41.6	4.1	42.607	P	16.11	280.82	8.594
NVAR	20500785	7.0284	-82.2529	0.0	1999-154:14.17.33.3	4.6	45.128	P	53.43	124.84	12.197
NVAR	20349721	53.7654	171.1972	24.3	1999-054:12.23.45.8	4.3	49.175	P	18.47	303.18	14.956
NVAR	20345538	14.9705	-60.5649	0.0	1999-050:11.57.47.9	4.2	55.662	P	29.66	105.72	15.260

Table 6.3.2. NVAR events used for TM tuning

STA	ORID	LAT	LON	DEPTH	UTM	MB	DELTA	PHASE	SNR	AZIMUTH	VEL
NVAR	20412001	24.4444	-46.3154	0.0	1999-096:04.51.05.4	5.0	61.572	P	21.00	83.41	14.575
NVAR	20393571	45.4446	149.9837	0.0	1999-080:13.32.29.6	4.4	64.970	P	19.73	285.77	9.668
NVAR	20444407	39.9178	145.3659	32.1	1999-108:20.41.16.4	4.0	70.790	P	23.51	278.19	9.450
NVAR	20361224	35.6290	141.7378	0.0	1999-061:07.12.17.6	4.7	75.621	P	30.76	283.12	19.221
NVAR	20350071	-21.3870	-173.7238	0.0	1999-054:18.56.50.4	4.8	78.988	P	68.10	212.54	13.781
NVAR	20367904	-34.5330	-69.3680	0.0	1999-064:03.35.14.5	4.9	85.604	P	21.27	164.69	16.450
NVAR	20408199	-19.2563	166.7876	0.0	1999-092:19.56.18.7	4.8	90.558	P	29.29	239.53	27.041
NVAR	20450367	-6.1334	150.8353	0.0	1999-113:09.58.02.6	4.8	94.441	P	38.38	245.01	21.372
NVAR	20413385	-6.5398	147.1112	0.0	1999-096:08.22.11.1	5.6	97.609	P	18.68	246.87	22.783
NVAR	20492167	12.8058	124.8997	44.0	1999-145:03.38.58.6	4.9	102.067	P	16.07	283.10	24.352
NVAR	20380686	2.6283	125.8539	86.1	1999-075:03.32.14.8	5.2	108.289	PKKP	22.70	122.42	15.237
NVAR	20382093	.0094	124.3615	57.8	1999-077:01.58.59.8	5.2	111.134	PKiKP	20.98	239.12	26.467
NVAR	20349505	-9.0232	112.5775	0.0	1999-054:05.45.58.2	4.9	125.868	PKP	16.34	276.90	34.571
NVAR	20368010	-5.8123	107.5961	326.0	1999-066:01.32.28.8	4.5	127.306	PKP	24.25	238.12	115.169
NVAR	20401468	-4.0128	87.1478	0.0	1999-088:06.17.58.3	5.3	138.633	PKhKP	15.01	281.21	17.318
NVAR	20500792	-8.5092	38.8420	0.0	1999-154:11.09.42.0	4.1	143.791	PKP	19.43	82.00	23.156
NVAR	20483009	-52.1677	20.3014	0.0	1999-137:00.30.33.1	4.3	148.270	PKPbc	16.53	124.22	23.300
NVAR	20450290	-27.9021	26.6636	0.0	1999-112:22.19.38.1	5.3	149.017	PKP	92.39	129.16	23.825
NVAR	20468597	-11.2676	66.1475	0.0	1999-126:06.54.45.8	4.6	152.660	PKPbc	35.62	266.08	17.035
NVAR	20417069	-41.9041	84.3861	0.0	1999-099:08.16.34.6	5.1	162.324	PKP	17.10	216.06	39.009

Signal-to-noise ratio vs. distance

We would like the TM procedure for estimating the network detection capability to resemble the IDC procedure for estimating m_b. At the IDC, a third order Butterworth filter with a passband between 0.8 and 4.5 Hz is applied to the data prior to the estimation of signal amplitude and period. The same prefilter should ideally be applied prior to the generation of the STA envelopes, but we also have to take into consideration the frequency band where we expect the highest SNR.

In Figures 6.3.1 and 6.3.2 we have plotted the average log(STA) for all noise segments preceding the P-phases versus frequency to see if there are noise peaks that should be avoided. It is apparent that for both stations there are increased noise levels above 2.0 Hz. To find the frequency range in which we expect the highest SNR, we have plotted the SNR (STA/LTA) measured in narrow frequency bands vs. the distance to the events in Figures 6.3.3 and 6.3.4. For each event we have normalized the maximum SNR to 50 dB. For both BRAR and NVAR we find the maximum SNR below 3.0 Hz at all distances. For the close distance range, good SNR is found up to 5 Hz.

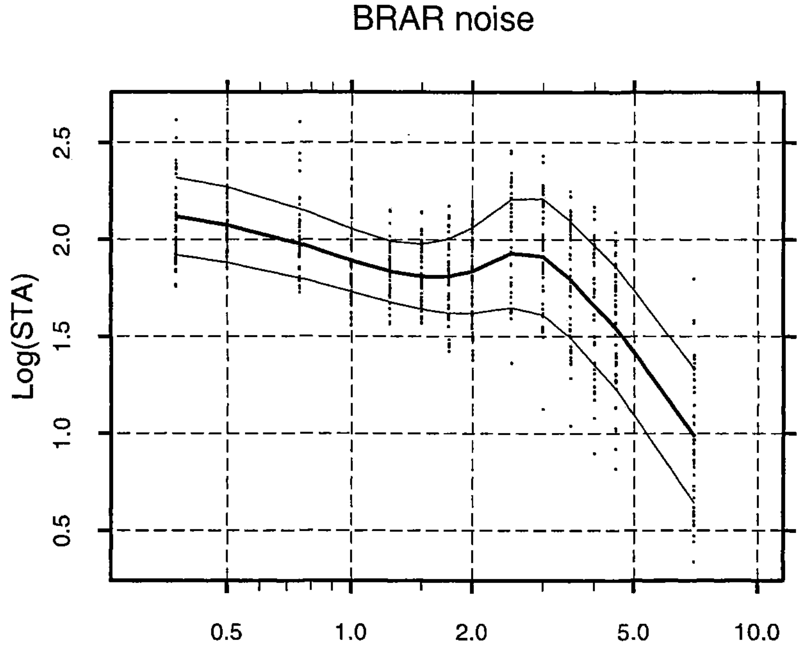

Fig. 6.3.1. Average narrowband log(STA) of the BRAR noise segments plotted versus frequency. Lines $\pm 1\sigma$ *around the mean are also shown.*

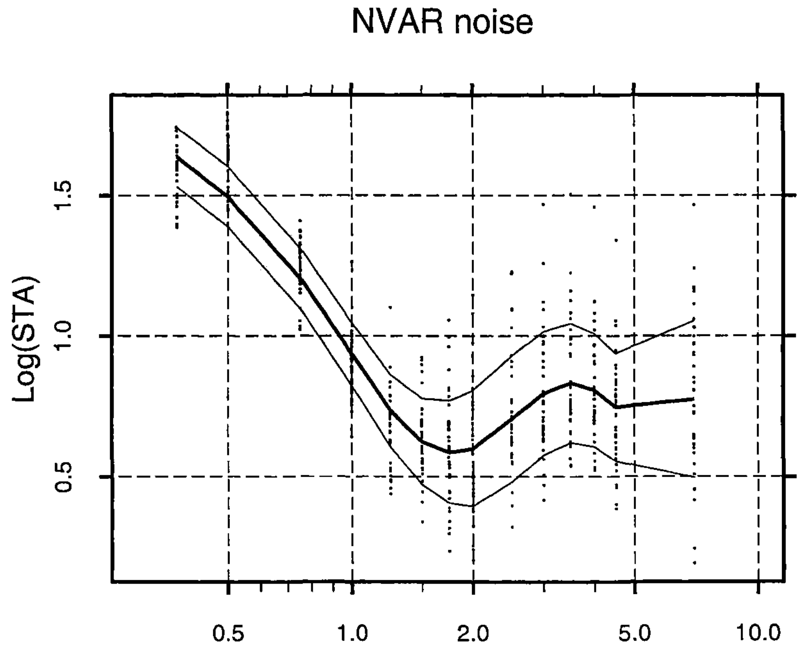

Fig. 6.3.2. Average narrowband log(STA) of the NVAR noise segments plotted versus frequency. Lines $\pm 1\sigma$ *around the mean are also shown.*

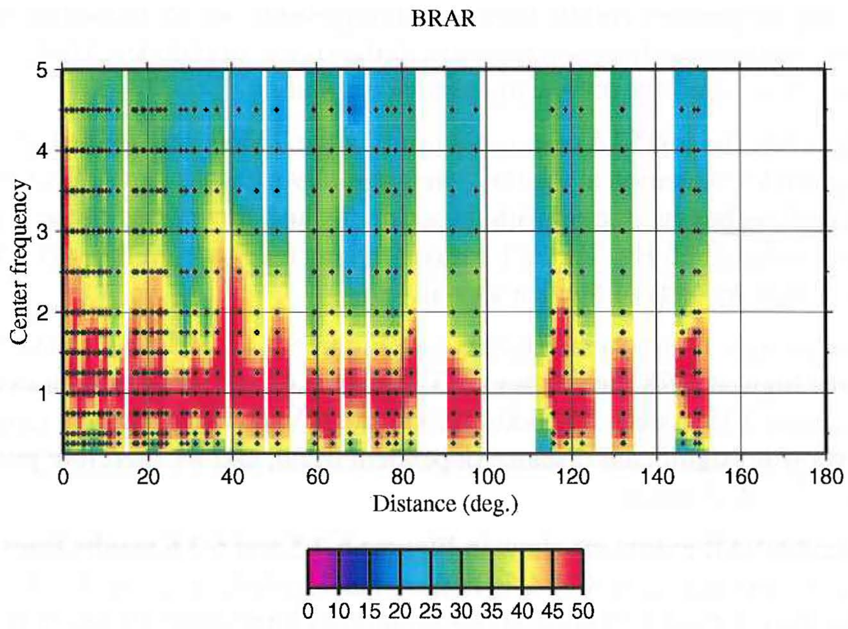

Fig. 6.3.3. SNR (STA/LTA) of BRAR events versus distance for events recorded at BRAR. The maximum SNR is normalized to 50 dB.

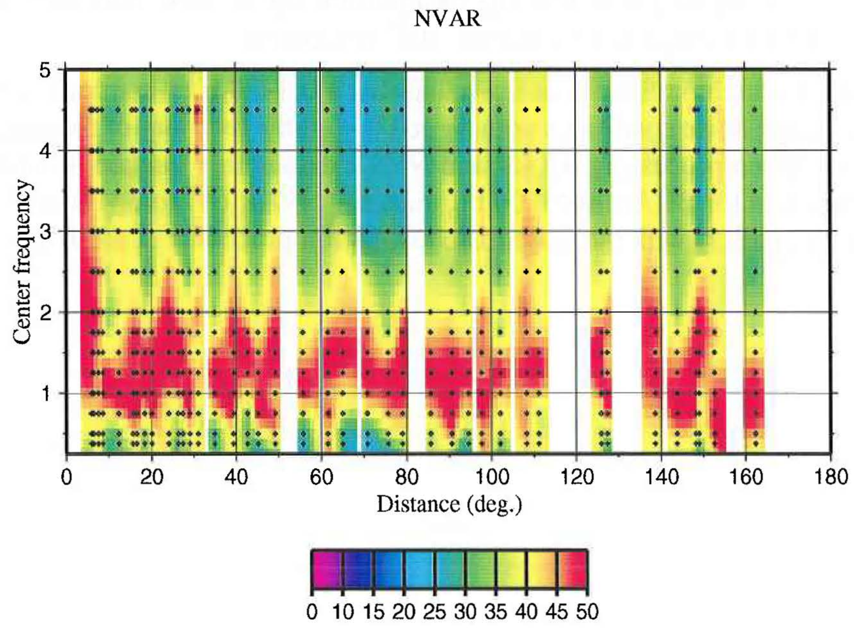

Fig. 6.3.4. SNR (STA/LTA) of NVR events versus distance for events recorded at NVAR. The maximum SNR is normalized to 50 dB.

Prefiltering

When choosing the prefilter cutoffs from the tuning events, we try to balance low amplitudes during noise conditions with a good recovery of the signal amplitudes. The frequencies may be different from those used for routine magnitude estimation.

To be able to relate the log(STA) estimates used by the TM system to the log(A/T) estimates used for magnitude estimation at the IDC, we manually measure log(A/T) of the tuning events. A/T is measured on beams steered with the azimuths and slownesses of the P-phases, and filtered between 0.8 and 4.5 Hz. The A/T measurements are made on the maximum amplitude occurring within 8 seconds of the first arrival.

Based on the average noise characteristics (see Figures 6.3.1 and 6.3.2) and the frequency range with the highest SNR (see Figures 6.3.3 and 6.3.4), we will test a series of filters for subsequent use in the TM system. For both BRAR and NVAR, the frequency ranges with maximum SNR show no significant distance dependent trend, and we therefore propose to use the same prefilter for all distances.

For BRAR and NVAR events we show in Figures 6.3.5 and 6.3.6 results from comparing the reference measurements in the 0.8-4.5 Hz filter band with the $\log((\pi/2) \cdot STA \cdot calib)$ measurements in three different filter bands (several other filters have also been tested). This average difference is later referred to as ATcomp. Mean (ATcomp) and Median give the average difference for the events. St.dev. gives the standard deviation of the differences and Noise gives the average STA level of the preceding noise.

For both stations we see that for STAs measured in the 0.8-4.5 Hz filter band (lower panel) there is, as expected, a very good correspondence with the reference A/T values. The mean difference for BRAR is only -0.01 m_b units with a standard deviation of 0.06 and an average noise value of -0.06 (m_b units). For NVAR the mean difference is -0.06 units with a standard deviation of 0.15 and an average noise value of -0.67 (m_b units).

When deciding which prefilter to use, we find that a 0.8-3.0 Hz filter band best combines low amplitudes during noise conditions with a good and stable recovery of the signal amplitudes for both stations. When processing BRAR and NVAR data in this frequency band we should subtract 0.01 m_b units for BRAR and 0.06 m_b units for NVAR (ATcomp) from the estimates to make them compatible with the magnitude estimation procedure at the IDC.

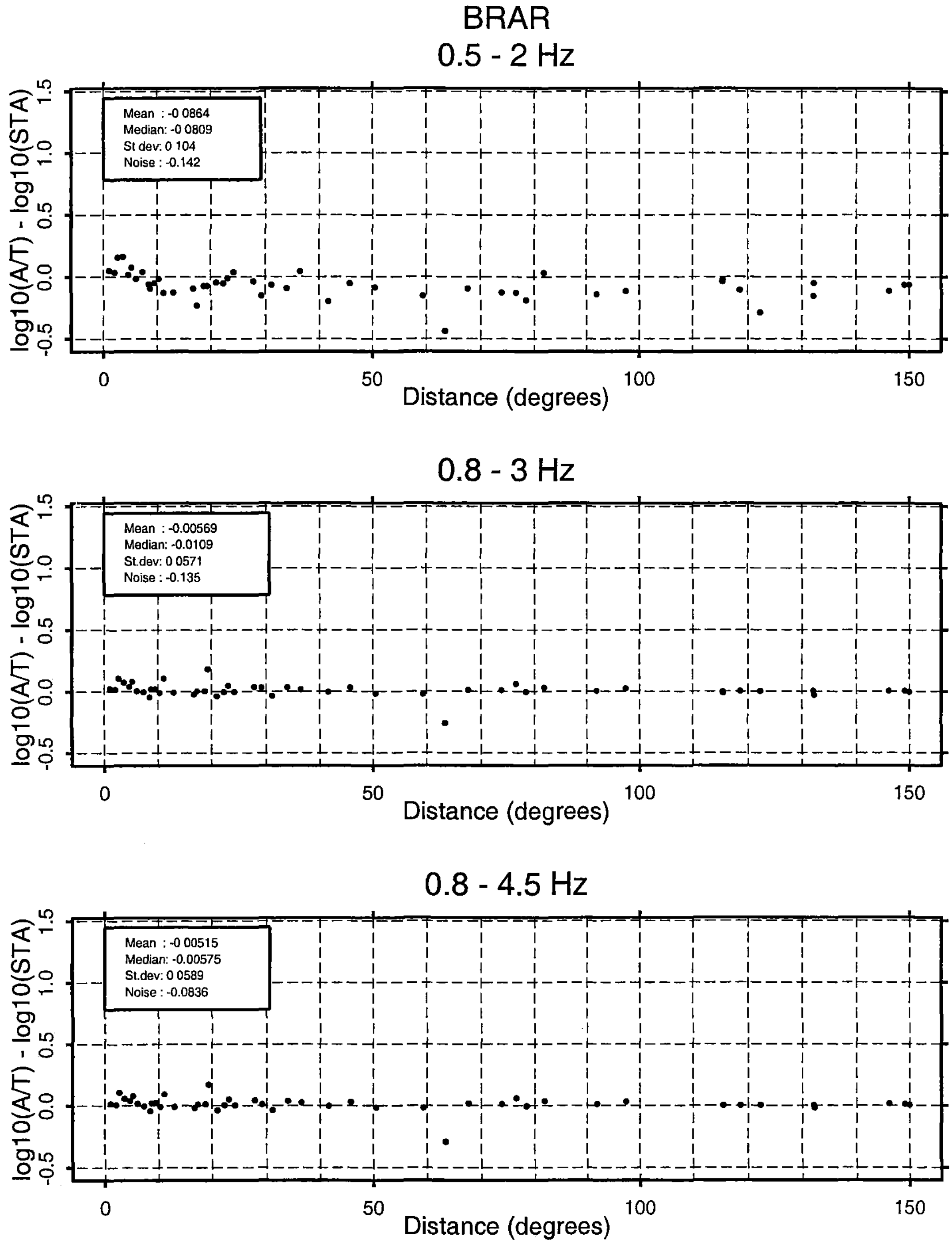

Fig. 6.3.5. *Panels showing the differences between the reference* $\log(A/T)$ *measurements (0.8-4.5 Hz) and* $\log((\pi/2) \cdot STA \times calib)$ *measured in three different filter bands. All tuning events at BRAR have been considered. The mean and median differences and standard deviations are shown for the events along with the average STA level of the preceding noise.*

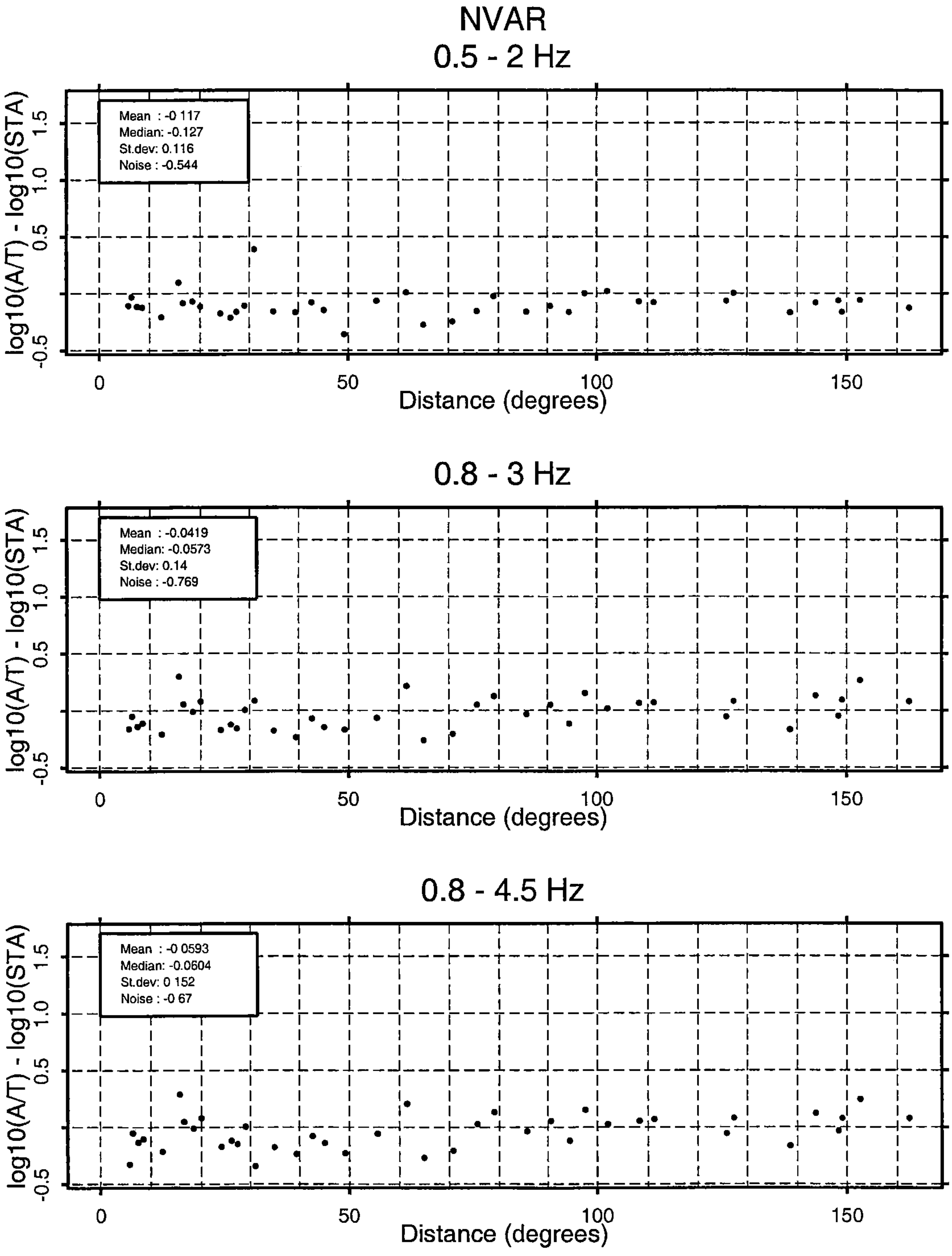

Fig. 6.3.6. *Panels showing the differences between the reference* $\log(A/T)$ *measurements (0.8-4.5 Hz) and* $\log((\pi/2) \cdot STA \times calib)$ *measured in three different filter bands. All tuning events at NVAR have been considered. The mean and median differences and standard deviations are shown for the events along with the average STA level of the preceding noise.*

Signal Loss and Mis-steering

As outlined in the Threshold Monitoring Operations Manual (Taylor et. al., 1998), we need to have available estimates of the expected beamforming signal loss as a function of the mis-steering of the beams for each array. This is done by measuring the signal loss as a function of the mis-steering of the filtered beams, according to the relation:

sloss=(beam STA)/(Average STA of individual sensors)

where STA is taken to be the maximum within 8 seconds of the first arrival.

In Figure 6.3.7 we show the signal loss as a function of mis-steering for all BRAR events. As discussed in the preceding section, the prefilter passband 0.8-3.0 Hz was applied to the data. We see from the figure that the average signal loss for correct beam steering is 0.43 dB, and that additional 3 dB signal loss is expected to be found at a mis-steering of 0.148 s/km.

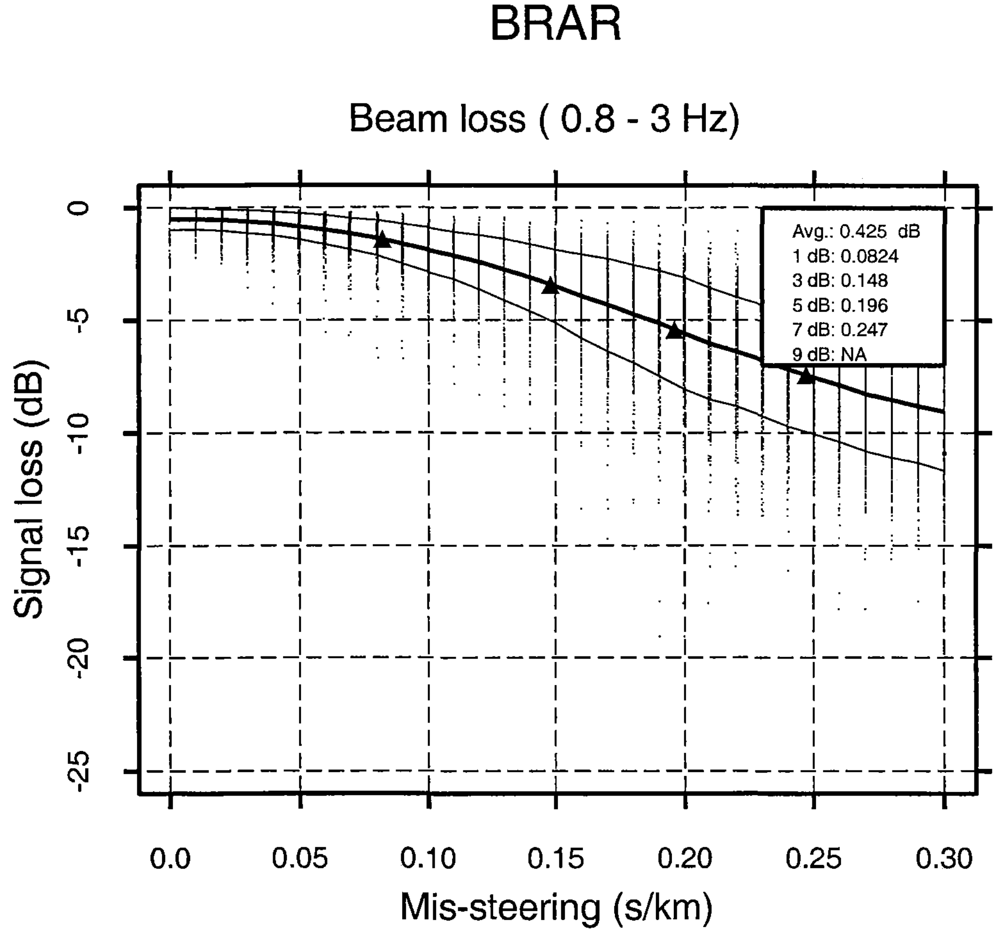

Fig. 6.3.7. *Signal loss for BRAR events prefiltered in the passband 0.8-3.0 Hz. The three lines show the average and the 1 σ levels of the signal loss. For no mis-steering the average signal loss is 0.43 dB. An additional 3 dB signal loss is expected at a mis-steering of 0.148 s/km.*

In Figure 6.3.8 we show the signal loss as a function of mis-steering for all NVAR events, again for beams filtered in the passband 0.8-3.0 Hz. The average signal loss for correct beam steering is 1.05 dB, and that additional 3 dB signal loss is expected to be found at a mis-steering of 0.086 s/km.

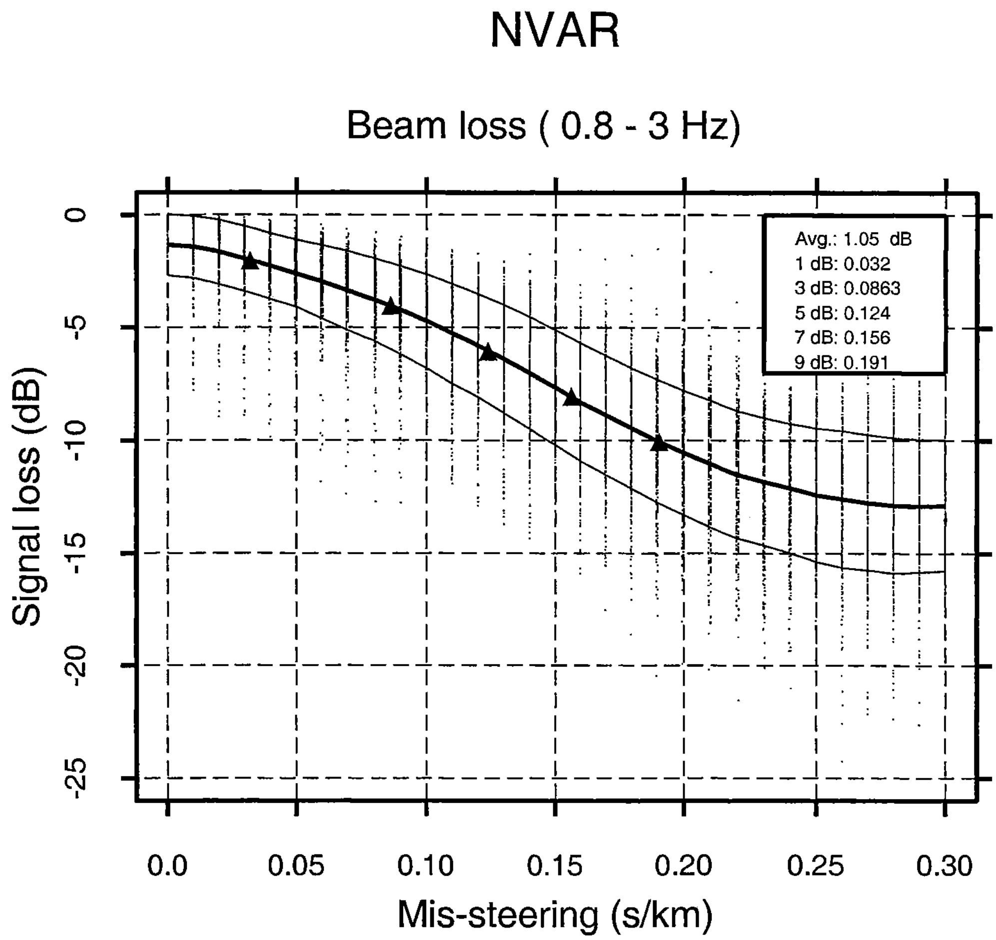

Fig. 6.3.8. *Signal loss for NVAR events prefiltered in the passband 0.8-3.0 Hz. The three lines show the average and the 1 σ levels of the signal loss. For no mis-steering the average signal loss is 1.05 dB. An additional 3 dB signal loss is expected at a mis-steering of 0.086 s/km.*

Beam Deployment

According to the IASP91 travel-time tables, the P phases used for estimation of network detection thresholds span the slowness range 0.0-0.124 s/km. According to Figure 6.3.7, the BRAR beams in this distance range have an expected 3 dB signal loss at a mis-steering of 0.148 s/km, such that only **one** beam with zero slowness is sufficient for covering the slowness area of interest (i.e., 0.0-0.124 s/km). The BRAR array has currently only six elements covering an aperture of about 2 km. Because of the relatively few sensors involved, beamforming require little computer resources. We have therefore decided to add four additional beams to the one required for complete coverage. In this way, signal loss due to mis-steering of the beams should be within 1 dB. The steering parameters of the BRAR beams are given in Table 6.3.5.

For NVAR beams we expect the 3 dB signal loss at a mis-steering of 0.086 s/km (see Figure 6.3.8). The procedure for deploying the beams is illustrated in Figure 6.3.9, where the dashed circles with radii of 0.086 s/km (3 dB level) are fitted within the slowness range 0.0-0.124 s/km. The center points of the small circles correspond to the steering parameters of the beams.

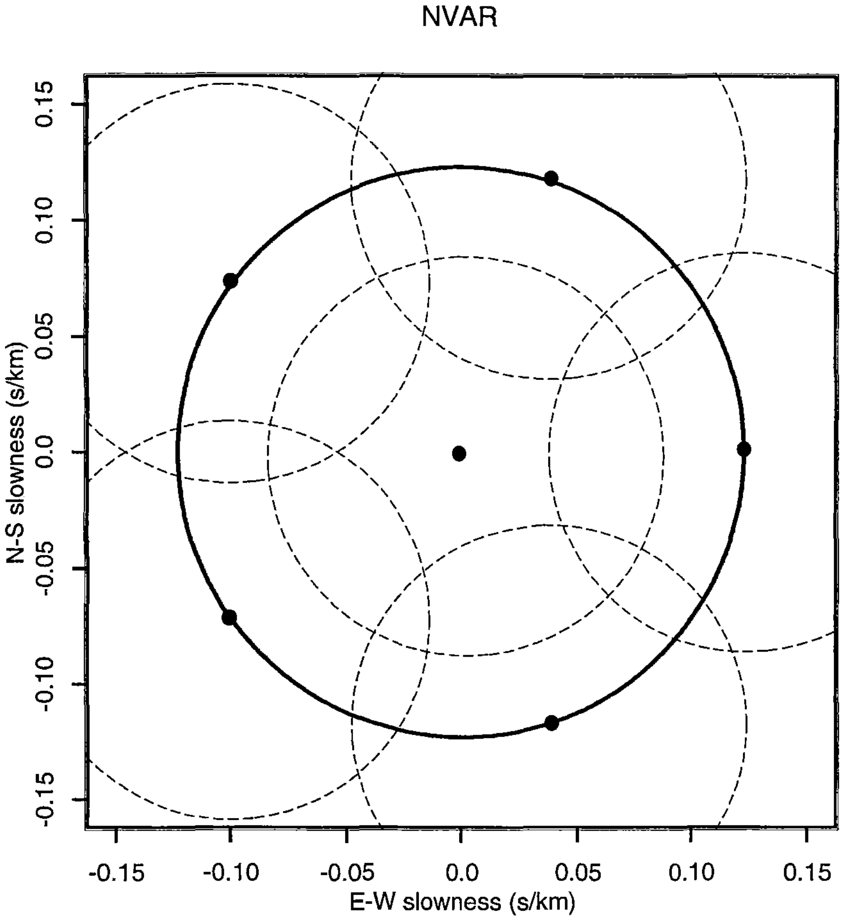

Fig. 6.3.9. *NVAR beam deployment used in the TM system for assessing the detection capability in the distance range 0-180 degrees. The area within the large circle corresponds to the expected slowness range of P-phases from surface events in this distance range. In order to ensure complete coverage within the 3 dB level, it was necessary to deploy 6 beams, represented by the centers of the dashed circles. The radius of each small circle is 0.086 s/km, corresponding to the expected mis-steering associated with the 3 dB signal loss.*

Details on the tuned processing parameters for BRAR and NVAR are given in Tables 6.3.3-6.3.5 below.

Table 6.3.3: Definitions of Array Configurations

Array	Configuration	sta_chan
BRAR	vertical	BR01_sz BR02_sz BR03_sz BR04_sz BR05_sz BR06_sz
NVAR	vertical	NV01_sz NV02_sz NV03_sz NV04_sz NV05_sz NV06_sz NV07_sz NV08_sz NV09_sz NV10_sz

Table 6.3.4: TM Tuning Parameters

Array	Distance interval (deg)	Config.	Frequency band (Hz)	A/T correction (m_b units)	Signal loss (dB)	3 dB level (s/km)	Number of beams
BRAR	0-180	vertical	0.8 - 3.0	−0.011±0.057	0.425	0.148	5
NVAR	0-180	vertical	0.8 - 3.0	−0.057±0.140	1.050	0.086	6

Table 6.3.5: Beam Steering Parameters

Array	Distance interval (deg)	Azimuth (deg) and slowness (s/km) of beams					
BRAR	0-180	0.0, 0.0	0.0, 0.123	90.0, 0.123	180.0, 0.123	270.0, 0.123	
NVAR	0-180	0.0, 0.0	0.0, 0.123	72.0, 0.123	144.0, 0.123	216.0, 0.123	288.0, 0.123

References

Taylor, L., T. Kværna, and F. Ringdal (1998). Threshold Monitoring Operations Manual. NORSAR Contribution No. 639.

T. Kværna
L. Taylor