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Frode Ringdal (ed.)

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6.2 Spectral characteristics of signals and noise at selected IMS stations

6.2.1 Introduction

The Primary Seismic Network of the International Monitoring System (IMS) has during the last couple of years been extended with new arrays and three-component stations. Based on the Threshold Monitoring (TM) concept, NORSAR has previously developed a system for continuous assessment of the global event detection capability of the Primary Seismic Network (Kværna and Ringdal, 1999; Taylor et al., 1998). In order to include new stations in the detectability calculations, the optimum processing parameters for each station have to be found. This station tuning process generally includes the following steps:

- Selection of recordings of regional and teleseismic events with geographically well-distributed locations
- Assessment of average noise spectra for the purpose of identifying spectral peaks that should be avoided in the continuous processing
- Determination of frequency passbands to be used when filtering the data. These passbands may be different for regional and teleseismic distances
- Determination of the beam deployment and signal loss of the arrays

For a set of 4 arrays and 3 three-component stations recently added to the IMS network, we will in the following present samples of the results from the tuning process, with emphasis on the noise spectra and the frequency ranges providing the best SNR.

6.2.2 Station and event distributions

A map of the arrays and three-component stations that have been tuned is shown in Figure 6.2.1. These are:

- AKASG (PS 45) in Ukraine, called the Malin array. This is a 23 element array with an aperture of 15 - 20 km.
- BRTR (PS 43) in Turkey, called the Keskin array. This is a 6 element array with an aperture of about 3 km.
- MKAR (PS 23) in Kazakhstan, called the Makanchi array. This is a 9 element array with an aperture of about 3-4 km.
- SONM (PS 25) in Mongolia, called the Songino array. This is a 10 element array with an aperture of about 4 km.
- KMBO (PS 24) in Kilimambogo, Kenya, is a three-component station.
- PPT (PS 18) in Pamatai, Tahiti, is a three-component station.
- THR (PS 21) in Teheran, Iran, is a three-component station.

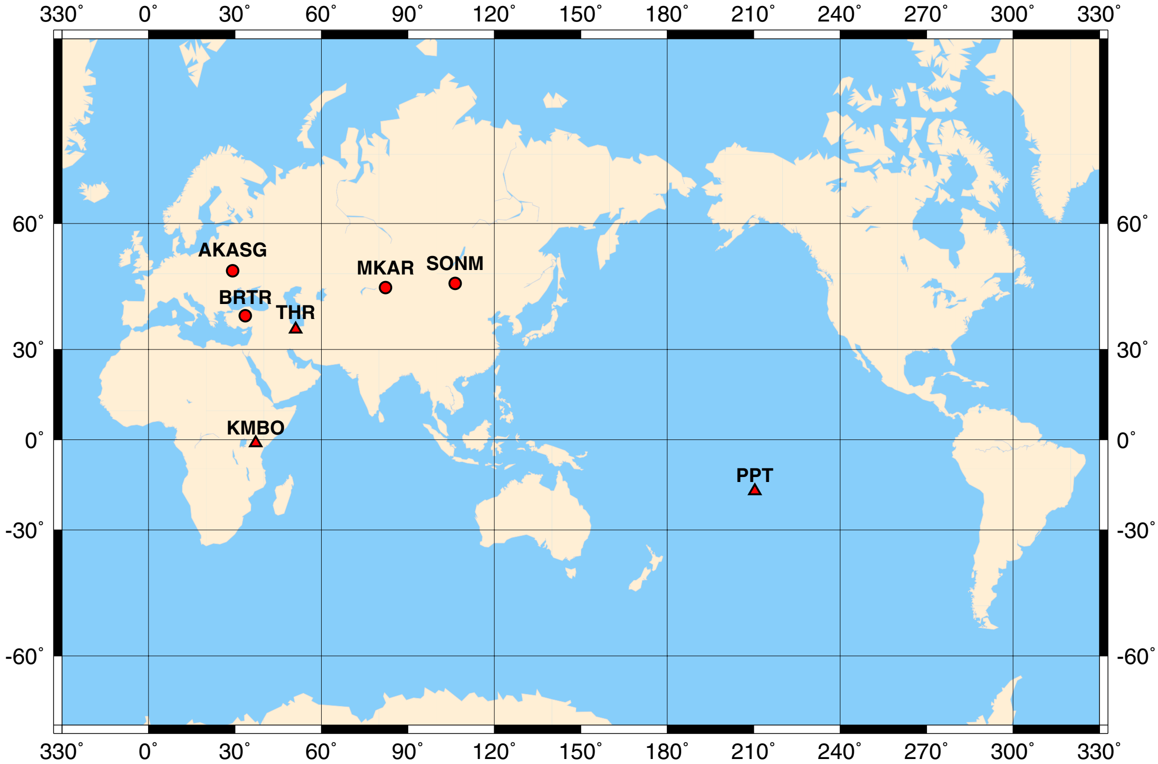


Fig. 6.2.1. Map of 4 arrays (filled red circles) and 3 three-component stations of the IMS Primary Seismic Network that are to be included in the TM-based detectability calculations.

For each of the arrays and three-component stations we have selected data for a set of geographically well-distributed shallow events. The event locations are shown in Figures 6.2.2 and 6.2.3. A basic assumption for the tuning procedure is that the characteristics of these events can be extrapolated down to the event detection threshold of the network, and we therefore have to avoid the largest magnitude events. On the other hand, we also have to require a sufficient signal-to noise ratio (SNR) such that the characteristics of the signals can be reliably estimated. We have therefore targeted the first-arriving P-phases with SNRs between 20 and 80. From searching the IDC Reviewed Event Bulletin for the time period October 2001 - October 2004 we ended up with 120 - 150 events for five of these stations. 89 events were found for station THR, whereas we were only able to find 33 events at station PPT, out of which several were deep events located in subduction zones. The reason for the small event population at PPT is the generally high background noise level and the low seismicity in the Central Pacific.

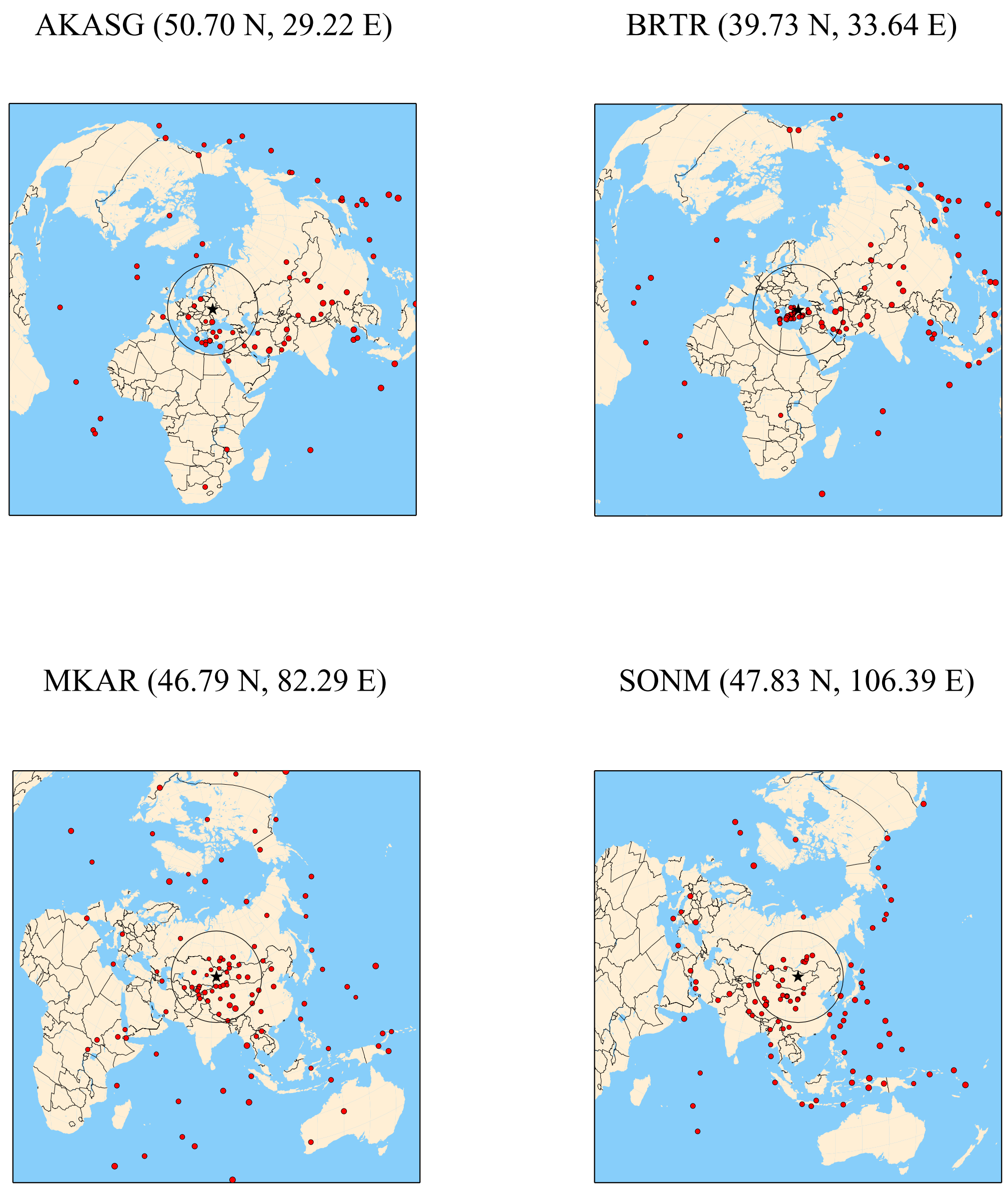


Fig. 6.2.2. Locations of the events used for tuning of the 4 arrays considered in this study. The circles encompassing the arrays represent a distance of 20 degrees.

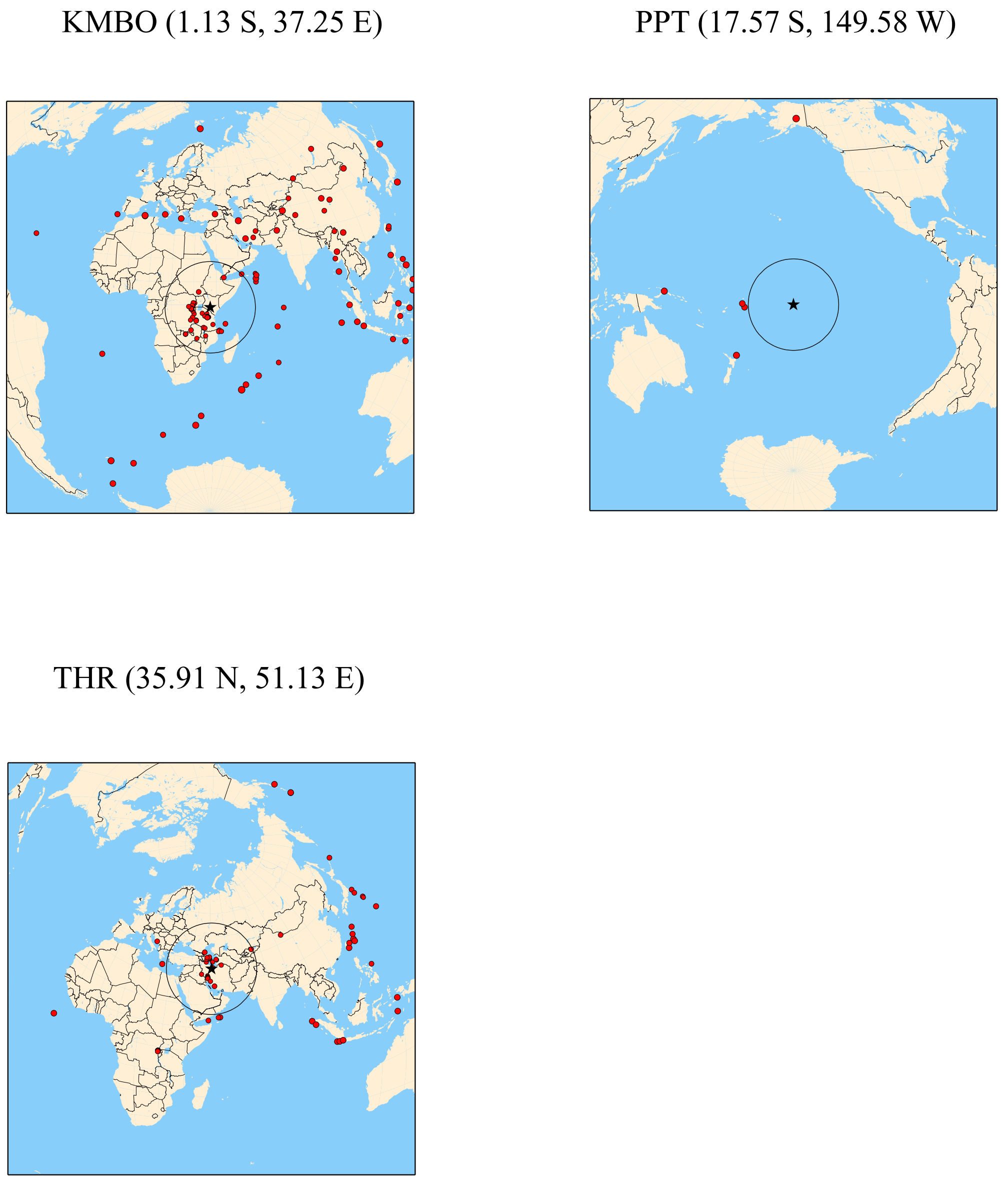


Fig. 6.2.3. Locations of the events used for tuning of the 3 three-component stations considered in this study. The circles encompassing the stations represent a distance of 20 degrees.

6.2.3 Noise and signal spectra

For each event in the database we have calculated the spectra of the noise preceding the P-phase. The noise windows started 50 second before the P onset and had a length of 40 seconds. The multitaper spectral method (Thomson, 1982) was used for estimation. For arrays we calculated the average noise spectra of all vertical-component channels, as well as the noise spectrum of the vertical component beam. The beam was steered with the azimuth and slowness of the arriving P-phase.

The motivation for this analysis was to get information about the absolute noise levels at the different stations and to identify frequencies or frequency ranges with particularly high noise levels. Figure 6.2.4 shows the displacement power spectra of the investigated arrays, both the average of the individual vertical component channels and of the beams. Figure 6.2.5 shows the displacement power spectra of the vertical component of the three-component stations. A summary of the spectral levels as compared to the Peterson noise models (Peterson, 1993) for given frequencies is given in Table 6.2.1. The numbers in red color represent values below the Peterson low noise model (PLNM). Such values are found on some of the array beams at selected frequencies.

Table 6.2.1. Displacement power levels at discrete frequencies

Frequency (Hz)												
	0.5	0.8	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Peterson Low Noise Model (Displacement Power, nm^2/Hz)												
	2.36e+01	5.60e-01	3.80e-02	1.49e-03	3.00e-04	2.00e-04	9.94e-05	1.07e-05	8.29e-06	5.86e-06	3.43e-06	1.00e-06
Average Noise Levels (Decibels above Peterson Low Noise Model)												
AKASG	9.81	13.67	18.14	19.89	21.05	25.68	27.43	24.77	24.37	25.40	24.59	26.57
BRTR	8.49	11.03	10.78	13.42	19.40	17.80	16.11	16.73	15.87	16.02	16.33	
MKAR	5.59	10.94	10.92	5.40	5.96	7.78	10.67	8.74	8.82	8.85	9.63	9.49
SONM	4.53	7.66	7.49	10.20	13.97	15.03	16.40	16.19	18.24	19.36	19.76	30.04
KMBO	9.56	11.98	10.55	8.67	11.72	14.36	20.78	28.27	32.50	33.74	30.31	27.41
PPT	34.99	38.85	37.30	39.20	34.11	37.11	37.58	38.20	37.62	42.13	39.29	42.59
THR	3.27	7.51	7.49	8.71	11.39	10.93	12.01	12.01	9.87	10.14	12.01	13.00
Beam Noise Levels (Decibels above Peterson Low Noise Model)												
AKASG	-1.26	1.74	7.58	8.03	9.10	13.29	15.27	12.46	12.79	14.40	13.03	15.33
BRTR	5.33	5.95	3.80	5.02	11.48	10.20	8.64	8.47	7.96	8.49	8.59	
MKAR	3.68	6.57	5.64	-3.39	-3.91	-2.22	1.22	-0.78	-0.25	-0.27	0.45	0.42
SONM	2.52	3.30	0.86	-0.50	3.74	4.87	6.58	6.48	8.29	9.01	10.52	20.02

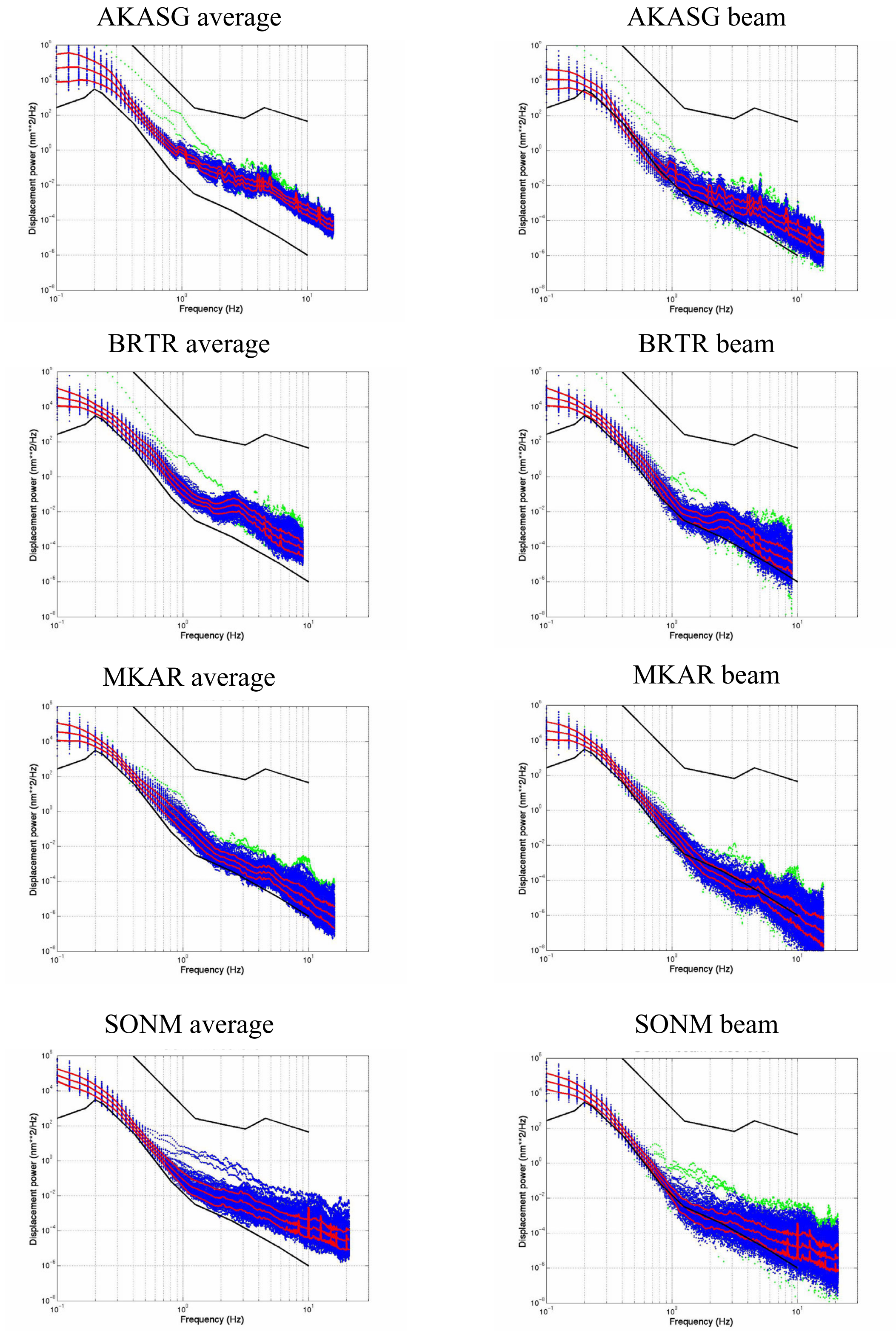
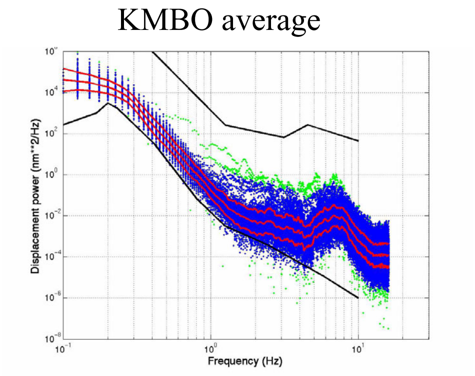
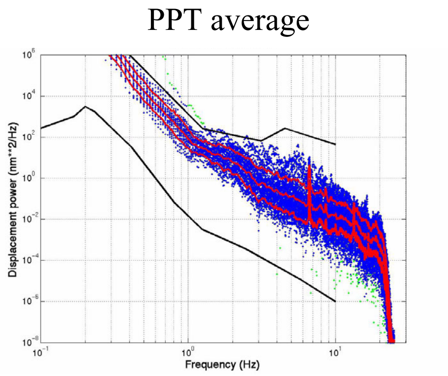


Fig. 6.2.4. Average displacement spectra (left) and beam spectra (right) of noise preceding the P-phases for the four arrays. The average ± one standard deviation of all noise samples are shown red. Green indicate spectral levels exceeding 3 standard deviations. The low and high Peterson noise models are indicated by black solid lines.





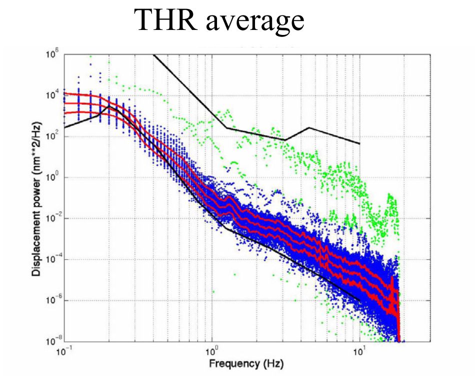


Fig. 6.2.5. Average displacement spectra of noise preceding the P-phases for the 3 three-component stations. The average ± one standard deviation of all noise samples are shown red. Green indicate spectral levels exceeding 3 standard deviations. The low and high Peterson noise models are indicated by black solid lines.

The spectra shown in Figures 6.2.4 and 6.2.5 provide information about the absolute noise levels at the different stations. However, continuous data processing is most of the time applied to uncorrected data, and the shape of the uncorrected noise spectra is not only dependent on the actual noise field, but also on the instrument response of the recording system. For estimation of the network event detection capability we need for each station to know the frequency range for which we usually have the best SNR, preferably combined with a good recovery of the signal amplitudes. Figure 6.2.6 shows the uncorrected array beam spectra together with SNR versus distance for the P-phases for the four arrays. The SNR of the beamformed P-signal was measured via the STA/LTA in narrow frequency bands. The SNR values were then normalized to the maximum, and some averaging was done when grouping the events into distance bins. Figure 6.2.7 shows similar plots for the three-component stations. For most stations we see that the highest SNR is found at generally low frequencies for teleseismic events, whereas for local and regional events the best SNR is generally found at higher frequencies. This is mostly a result of the attenuation of the high frequencies at larger distances, but the receiver site conditions, the local noise field and the instrument response also play a role in determining the frequency range for which we find the highest SNR.

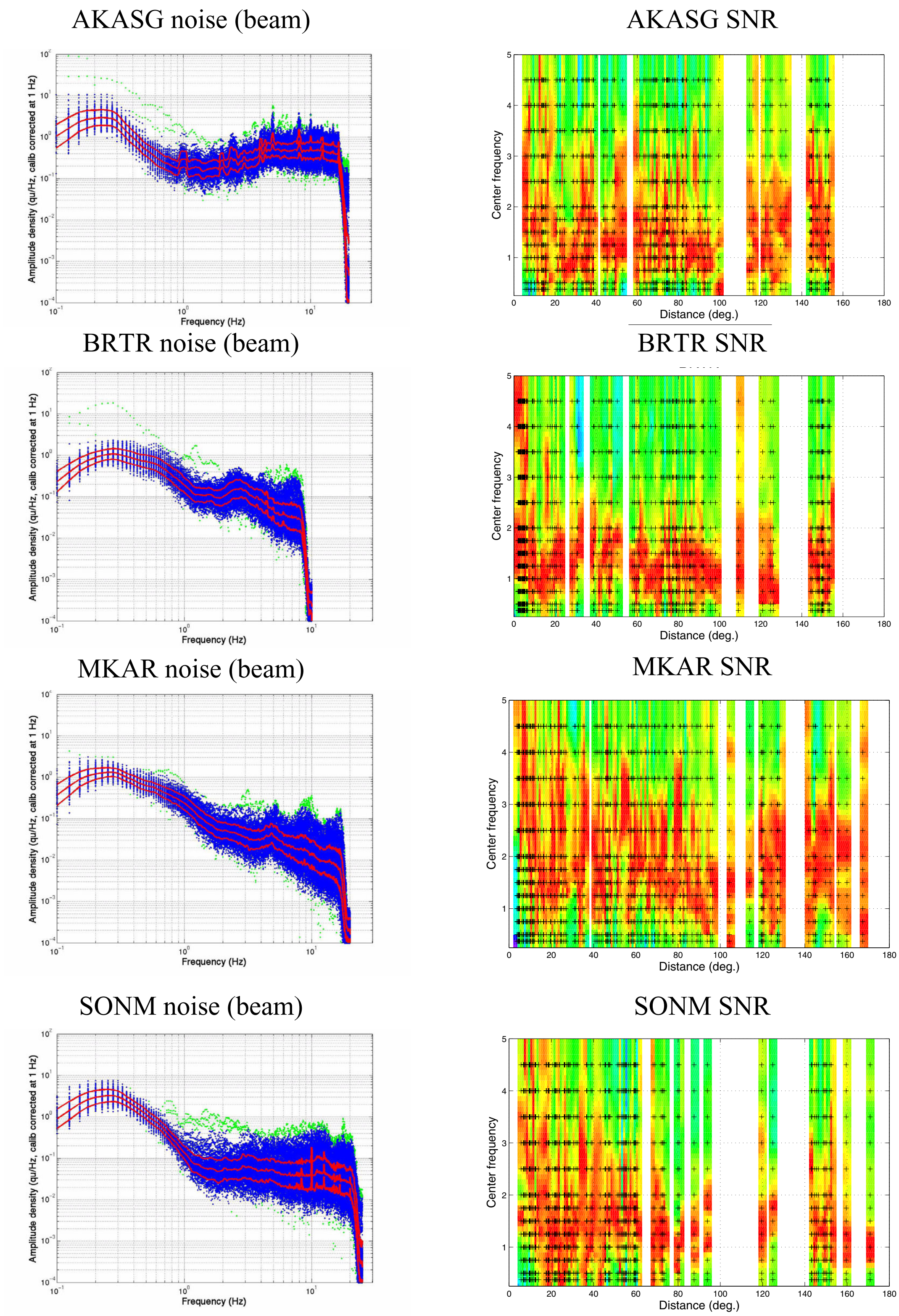


Fig. 6.2.6. Uncorrected beam noise spectra (left) and SNR vs. distance (right) for the P-phases for the four arrays. On the plots to the left, the average ± one standard deviation of all noise samples are shown red, while green indicate spectral levels exceeding 3 standard deviations. The plots to the right show the normalized SNR as a function of distance. The frequencies with the highest SNR are marked red.

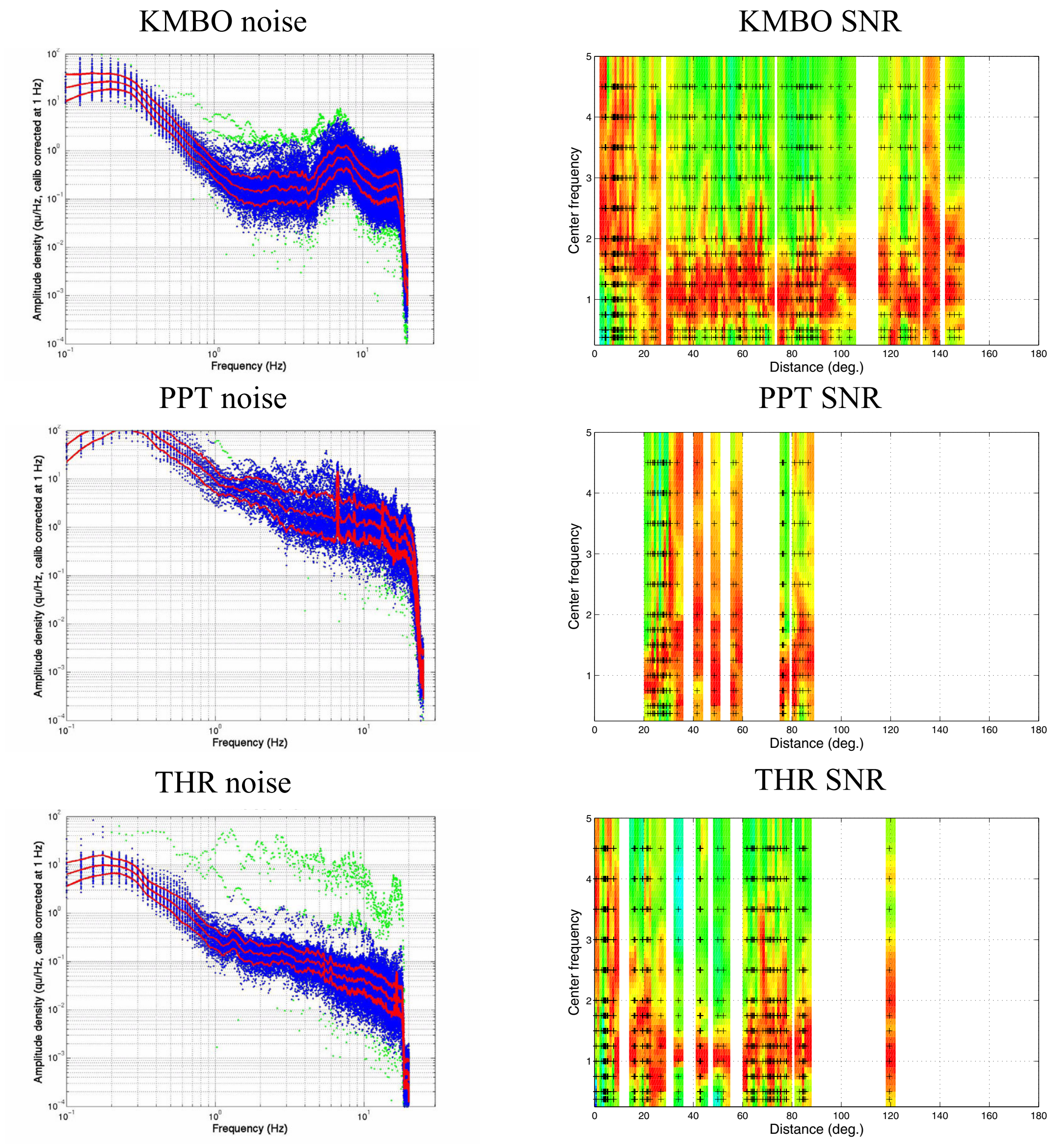


Fig. 6.2.7. Uncorrected noise spectra (left) and SNR vs. distance (right) for the P-phases for the 3 three-component stations. On the plots to the left, the average ± one standard deviation of all noise samples are shown red, while green indicate spectral levels exceeding 3 standard deviations. The plots to the right show the normalized SNR as a function of distance. The frequencies with the highest SNR are marked red.

6.2.4 Discussion

We will in the following discuss the noise and signal characteristics of the investigated arrays and three-component stations.

AKASG

Background Noise Levels:

The background noise levels at Malin, Ukraine (AKASG) ranges from about 10 dB above the Peterson Low Noise Model (PLNM) at 0.5 Hz increasing to about 25 dB above PLNM at 4 Hz. Above 4 Hz the background noise level stays about 25 dB above PLNM.

Beam Noise Levels:

AKASG is a 23 element array with an aperture of 15 - 20 km. With uncorrelated noise we would expect about 13 dB noise reduction by beamforming. The noise beam spectra of Figure 6.2.4 and the values given in Table 6.2.1 confirm this. As a result we find that the noise level after beamforming is lower than the PLNM below 1 Hz.

Noise Peaks

As seen from Figures 6.2.4 and 6.2.6 there are a number of pronounced peaks in the AKASG noise spectra (1Hz, 2 Hz, 2.5 Hz, 4 Hz, 8 Hz), which we assume are caused by nearby cultural noise sources.

Uncorrected spectra

The AKASG array is equipped with instruments that have a flat acceleration response in the higher frequency range. Consequently the uncorrected noise has relatively high levels above 4 Hz (see Figure 6.2.6). The noise peaks stand out clearly in the uncorrected spectra. Without introducing instrument response corrections, the frequency range between 1 and 2 Hz has the lowest noise levels.

SNR vs. distance

For distances larger than 20 degrees, the highest SNR is usually found between 1 and 2 Hz, but some of the teleseismic events have high SNR up to 3 Hz. For local/regional distances up to 20 degrees high SNR is observed up to 4 Hz.

BRTR

Background Noise Levels:

Between 0.5 and 2 Hz the background noise levels at Keskin, Turkey (BRTR) ranges from 8.5 to 13.5 dB above the Peterson Low Noise Model (PLNM). Between 2 and 3 Hz there is a relative increase in the background noise level from 13.5 to 19.5 dB above PLNM. For frequencies above 5 Hz we find average noise levels about 16 dB above PLNM.

Beam Noise Levels:

BRTR is a 6 element array with an aperture of about 3 km. With uncorrelated noise we would expect 7-8 dB noise reduction by beamforming. The noise beam spectra of Figure 6.2.4 and the values given in Table 6.2.1 confirms this for frequencies above 1Hz. For frequencies below 1 Hz less noise reduction if found through beamforming, indicating that the noise is correlated between the array sensors for such low frequencies.

Noise Peaks

As seen from Figures 6.2.4 and 6.2.6 there is a pronounced noise peak between 2 and 3 Hz, which we assume is caused by nearby cultural noise sources.

Uncorrected spectra

The BRTR array is equipped with instruments that have a flat velocity response above about 1 Hz. Because of the noise peak around 3 Hz, we find that there is a local minimum between 1.2 and 2 Hz in the uncorrected noise spectra.

SNR vs. distance

For distances larger than 15 degrees, we find the highest SNR between 0.8 and 2 Hz. For distances less than 10 degrees we also find high SNR is observed above 3 Hz.

MKAR

Background Noise Levels:

The background noise levels at the Makanchi array in Kazakhstan (MKAR) stays within 11 dB of the PLNM for the frequency range 0.2 - 10 Hz. In particular, the noise levels around 2 and 3 Hz is within 6 dB of the PLNM.

Beam Noise Levels:

MKAR is a 9 element array with an aperture of about 3-4 km. With uncorrelated noise we would expect about 9 dB noise reduction by beamforming. The noise beam spectra of Figure 6.2.4 and the values given in Table 6.2.1 confirms this for frequencies above 2 Hz, such that the beam noise level at MKAR fall below or close to the PNLM for these frequencies. For frequencies below 2 Hz less noise reduction is found through beamforming, indicating that the noise in this frequency range is correlated between the array sensors.

Noise Peaks

As seen from Figures 6.2.4 and 6.2.6 there is a small noise peak around 5 Hz.

Uncorrected spectra

The MKAR array is equipped with instruments that have a flat velocity response above about 1 Hz. The average uncorrected noise spectrum generally decreases from 0.3 to 15 Hz, except for the frequency range 3.5 - 5 Hz which is influenced by the small 5 Hz noise peak.

SNR vs. distance

For distances larger than 15 degrees, we find the highest SNR between 0.8 and 3.5Hz. For distances less than 10 degrees the highest SNR is observed above 2 Hz.

SONM

Background Noise Levels:

The background noise levels at the Songino array in Mongolia (SONM) stays within 8 dB of the PLNM for the frequency range 0.2 - 1 Hz. Between 2 and 9 Hz there is a relative increase in the noise levels from 10 to 20 dB above PLNM.

Beam Noise Levels:

SONM is a 10 element array with an aperture of about 4 km. With uncorrelated noise we would expect about 10 dB noise reduction by beamforming. The noise beam spectra of Figure 6.2.4 and the values given in Table 1 confirms this for frequencies above 1 Hz, such that the beam noise level at SONM is comparable to the PNLM in the 1 to 2 Hz range. For frequencies below 1 Hz less noise reduction is found through beamforming, indicating that the noise in this frequency range is correlated between the array sensors.

Noise Peaks

There are several pronounced noise peaks around 10 Hz.

Uncorrected spectra

The SONM array is equipped with instruments that have a flat velocity response above 1 Hz. The average uncorrected noise spectrum is almost constant in the frequency range 1.5 to 8 Hz.

SNR vs. distance

For distances larger than 80 degrees, we find the highest SNR between 0.8 and 2 Hz. For distances between 20 and 80 degrees the highest SNR is found between 0.8 and 3 Hz. For local and regional distances, the higher frequencies become more important.

KMBO

Background Noise Levels:

The background noise levels at the Kilimambogo station in Kenya (KMBO) stays within 15 dB of the PLNM for the frequency range 0.2 - 4 Hz. Between 4 and 6 Hz there is a large relative increase in the noise levels from 15 to 30 dB above PLNM.

Noise Peaks

There are no narrow noise peaks, but the frequency range from 4.5 to 10 Hz is characterized by high noise levels.

Uncorrected spectra

The KMBO station is equipped with instruments that have a flat velocity response above 1 Hz, and the high noise levels between 4.5 and 10 Hz stand out clearly.

SNR vs. distance

For distances above 20 degrees, we generally find the highest SNR between 0.8 and 2 Hz. For distances less than 20 degrees, generally high SNR is found in the frequency range 1.2 to 4.5 Hz.

PPT

Background Noise Levels:

The Pamatai station on Tahiti (PPT) has high noise levels in the entire investigated frequency band, varying between 35 and 40 dB above PLNM. The high noise levels are most likely caused by the proximity to the Pacific Ocean and man-made activity on the island of Tahiti.

Noise Peaks

There is a pronounced noise peak between 6 and 7 Hz, together with smaller peaks between 8 and 15 Hz.

Uncorrected spectra

Except for the 6-7 Hz range, the uncorrected PPT noise spectra generally decrease with increasing frequencies. The peak between 6 and 7 Hz stands out clearly.

SNR vs. distance

As previously explained we had difficulties finding a sufficiently large number of events at PPT that could be used for tuning purposes. A total of 33 events were found, having epicentral distances from 20 to 90 degrees from the station. In this distance range the best SNR was generally found in the frequency range 0.8 to 3 Hz.

THR

Background Noise Levels:

The Teheran station in Iran (THR) has relatively low noise levels in the entire investigated frequency band. The values vary from 3 dB above PLNM at 0.5 Hz up to 12 dB above the PLNM for frequencies higher than 3 Hz.

Noise Peaks

Station THR has a few smaller noise peaks, for example at 1.5 Hz and about 15 Hz.

Uncorrected spectra

Except for the 1.5 Hz range, the uncorrected THR noise spectra generally decrease with increasing frequencies. The peak at about 15 Hz stands out clearly.

SNR vs. distance

For distances above 20 degrees, we generally find the highest SNR between 0.8 and 2 Hz. For distances less than 20 degrees, generally high SNR is found in the frequency range 1 to 5 Hz.

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Tormod Kværna
Ulf Baadshaug