ARCHIPELAGO AMBIENT NOISE AND ITS DEPENDENCE ON WEATHER.

J Pihl Swedish Defence Research Agency, Stockholm, Sweden.

INTRODUCTION

Background

For passive surveillance sonar the main limiting factor is the ambient noise (AN). It is therefore important to know the AN level when the performance of a sonar is calculated. A common way to estimate AN is to use empirical relations between AN and sea-state, for example the Wenz curves, Figure 1

Earlier measurements[1-3] have shown that AN in the Baltic sometimes does not always follow the Wenz curves. One reason for this might be that the Baltic is very shallow, the mean depth is only 57 m. Another reason is the size – at higher sea states the distances are too short for a full fetch, especially for winds from east or west. And in the archipelago the fetch is almost always too short. This means that waves will not reach full height, and the AN will be lower.

The Purpose of the Measurements

For the Royal Swedish Navy, it is important to know the performance of its passive surveillance systems. For instance, in Anti-Submarine Warfare (ASW) with passive sonobuoys it is crucial to know the detection distance so that the buoys can be placed with the correct distance between them.

In September 2018, a large field trial was hosted by FOI, with several other countries participating, Figure 2. The purpose of the experiment was to test techniques and methods for autonomous underwater surveillance systems. As a “piggy-back experiment” a passive array was deployed. Signals from this array were recorded throughout the experiment, which lasted 16 days.

In Section 2 the experimental setup and equipment is described. The analysis methods are explained in Section 3, and the results are presented in Section 4. Conclusions and recommendations are given in Section 5.

EXPERIMENTAL SETUP

The PASS Array

The Passive Acoustic Surveillance System (PASS) is a line array developed by Omnitech Ltd, Canada, for FOI. It consists of 56 hydrophones spaced along the antenna cable in six linear acoustic apertures spanning 100 Hz to 3200 Hz[5]. The total length of the array is 112.5 m. The hydrophones are protected by a shroud and each element is directly connected to amplifiers and A/D converters. The digitized signals are then sent to shore by means of a fiber-optic cable and stored on hard discs. The sampling frequency was 30 ksamples/s and the resolution was 24 bits.

In the experiment the array was laid out on the bottom in a straight line, at a depth of 42 m.

The Weather Station

Weather was recorded using a weather station (Vaisala WXT536) that sampled wind speed, wind direction and rain among other variables. The sample rate was once per minute. Unfortunately, there were no measurements of wave heights

MEASUREMENT PROCEDURES

Research Objectives

The main goals for the AN experiment were the following:

- Record statistics on AN in the archipelago for as many sea states as possible.
- Analyze AN dependence on:
    - Wind speed
    - Wind direction
    - Rain

Data Processing in General

AN is recorded continuously with the PASS cable array lying on the bottom. From the raw signals the power spectrum densities (PSDs) are calculated with 1 Hz bin-width, one PSD per second. The PSDs are then saved to files and used in the further processing.

An important aspect of the analysis is to remove anthropogenic noise, as we want to study the AN dependence on the weather only. Therefore, an anthropogenic filter was constructed, which removed most of the disturbances above 100 Hz. The data was averaged (Welch spectrum method) over 1 minute for comparison with metrological data, which were sampled once per minute.

From this analysis various percentiles and histograms were plotted.

The Anthropogenic Filter

The purpose of the filter is to find recordings which are not contaminated by anthropogenic noise. Every PSD is filtered and treated separately, which minimizes the influence of disturbances, especially those which are transient.

Only signals above 100 Hz are analyzed, as the AN below this frequency almost always is contaminated by shipping noise.

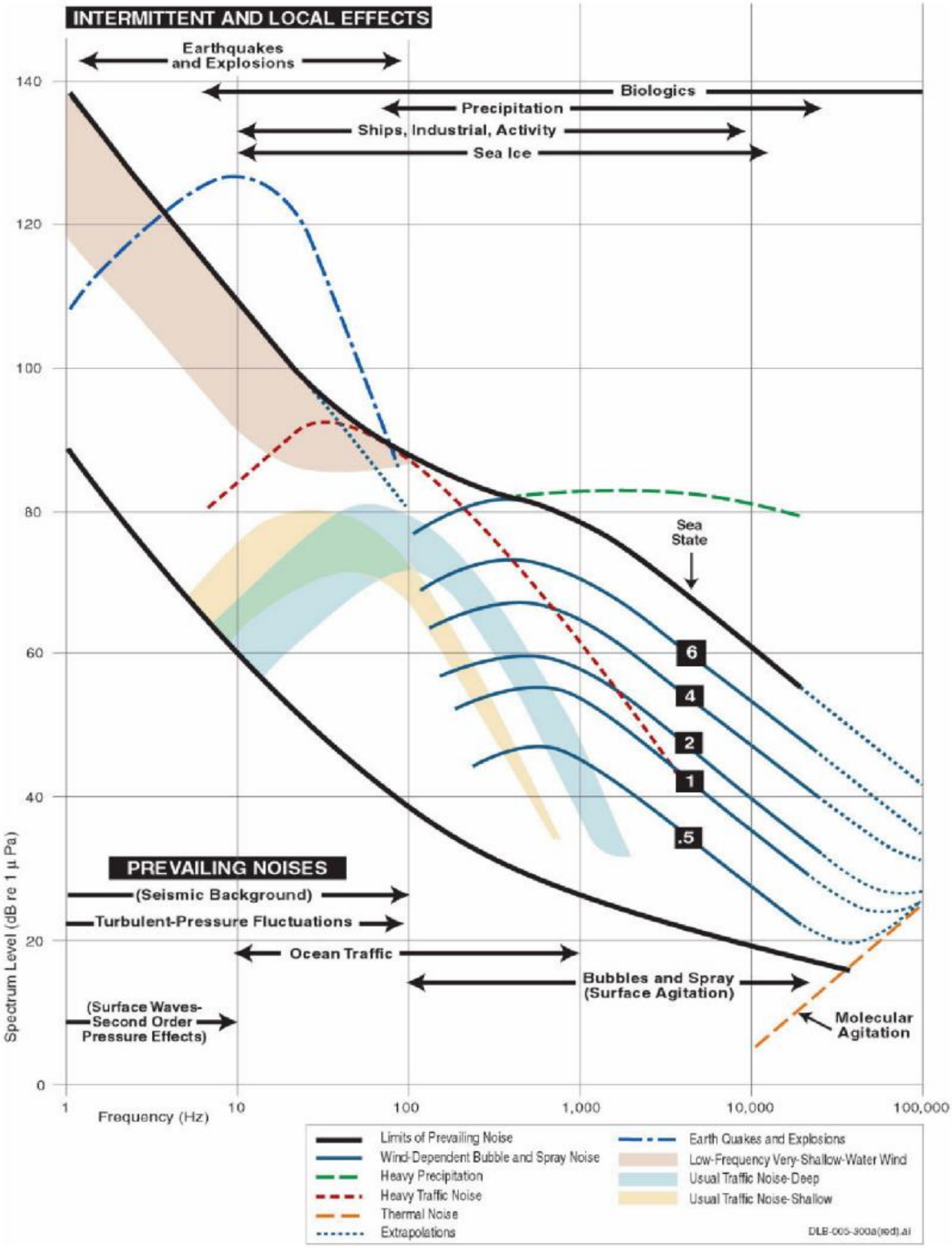

Figure 1: Ambient noise levels as a function of sea state and other sources [4].

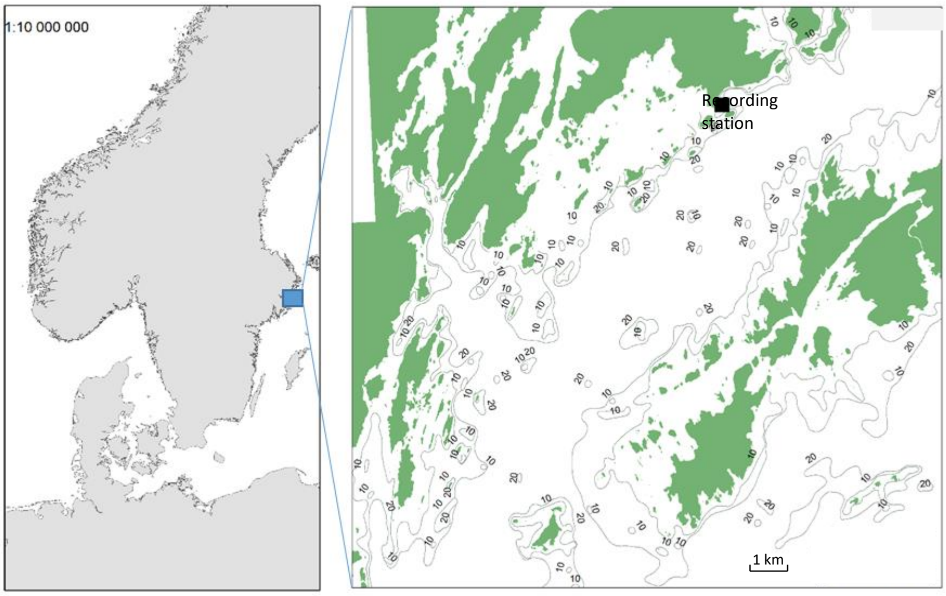

Figure 2: The experimental site in the Stockholm archipelago. The array was deployed within 1km from the recording station.

The anthropogenic filter has several detectors:

- Narrow band signals. As we do not know any weather generated noise which is narrow band, we regard all these as anthropogenic. However, if the level is low (a few dB above noise), we keep the PSD as the influence in the final analysis will be negligible.
- Underwater communication signals. These signals from the underwater network is easily detected, and the PSDs are discarded.
- Broad band disturbances. Temporal broad band disturbances, detected as “bumps” above the typical noise curve, usually comes from shipping.
- Number of spectra. As we calculate Welch spectra once per minute, there cannot be too many spectra missing. Hence one-minute averages that contains too few spectra are not included in the statistical analysis.

An example of the filter processing is given in Figure 3 below.

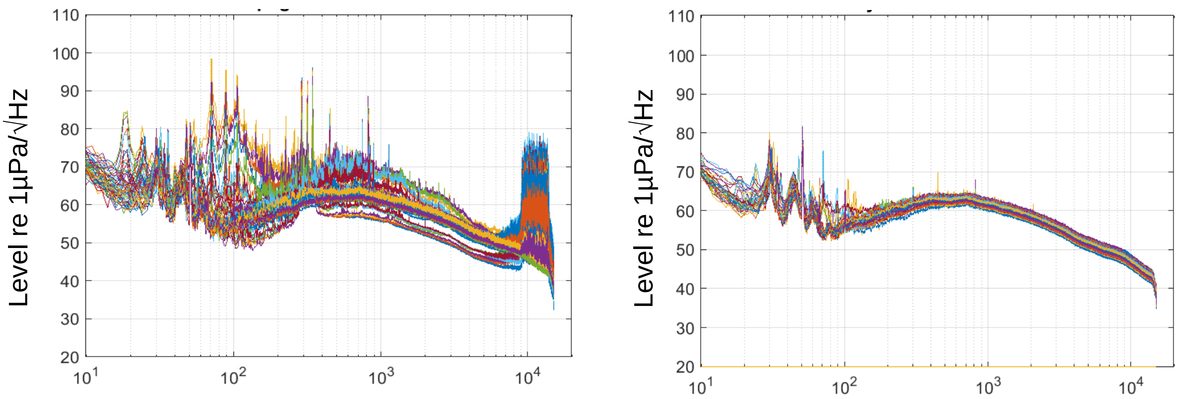

Figure. 3: An example of the anthropogenic filter process. Left: raw data, right: filtered data. Please note that the filter only operates on signals above 100 Hz.

RESULTS

Wind and Speed Dependence

An overall picture of AN dependence on wind speed is given in Figure 4. As can be seen, there is good correlation between noise levels and wind speed for all frequencies. There are some “spikes” in the AN which do not occur in the wind data. Presumably, this is due to anthropogenic disturbances which have not been detected by the anthropogenic filter.

In Figure 5 the median AN levels are plotted as a function of sea-state. Further examples and comparisons with Wenz and Imat levels are given in Figure 6. (Imat is a sonar performance prediction program developed by the US Navy, which has its own AN function). For the lower sea-state, 2, the median is close to the Wenz curve. But for the higher sea-state, 7, the Wenz curve is above even the 95% percentile.

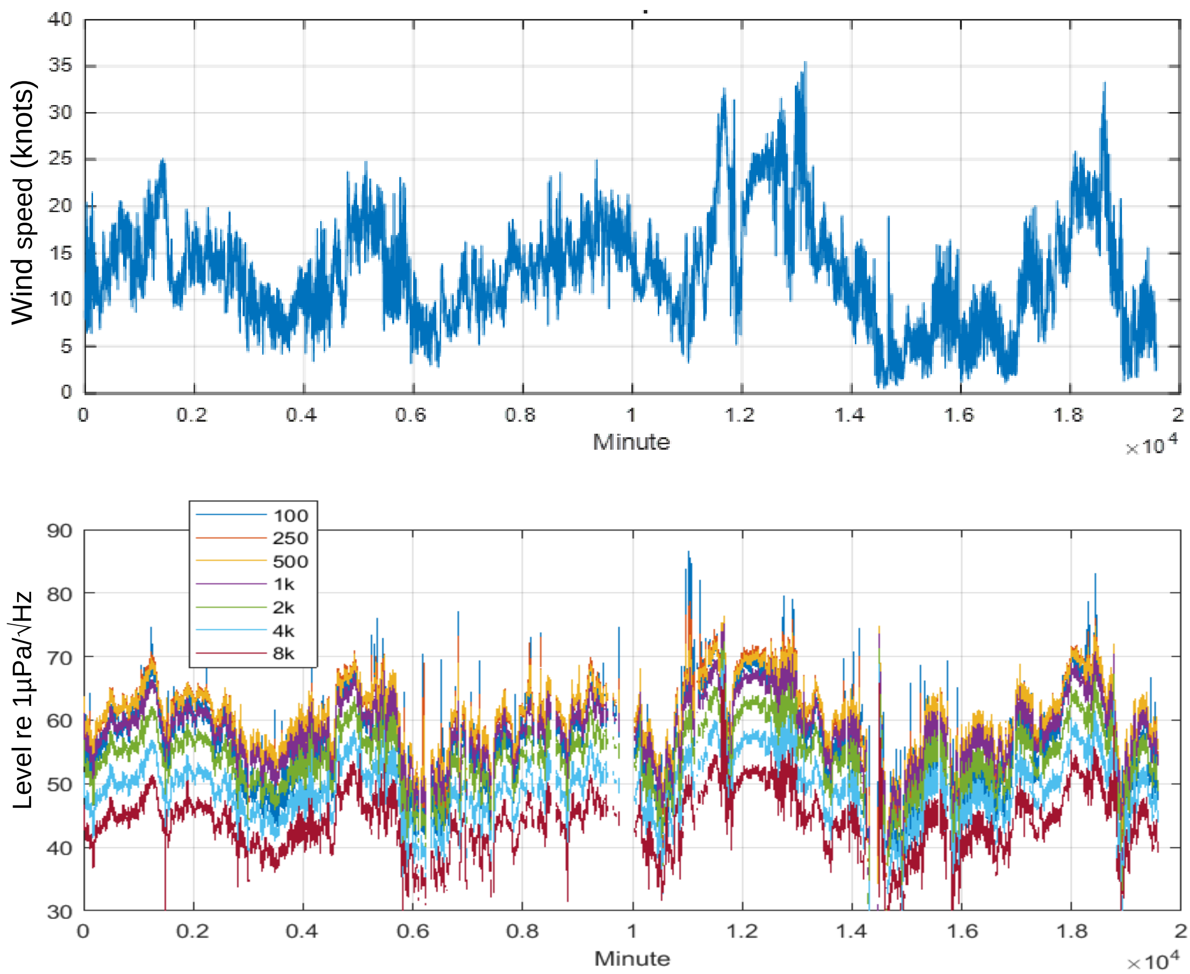

Figure 4: Wind speeds (upper part) and octave band levels for 7 octaves,100 Hz – 8k, (lower part) during the 16 days experiment.

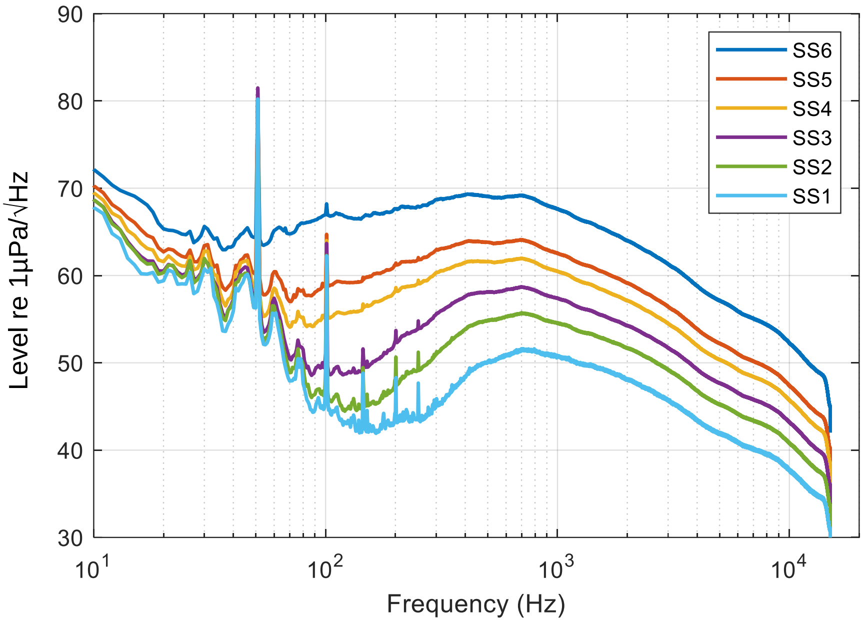

Figure 5: Median values (50th percentile) of ambient noise as a function of sea-state.

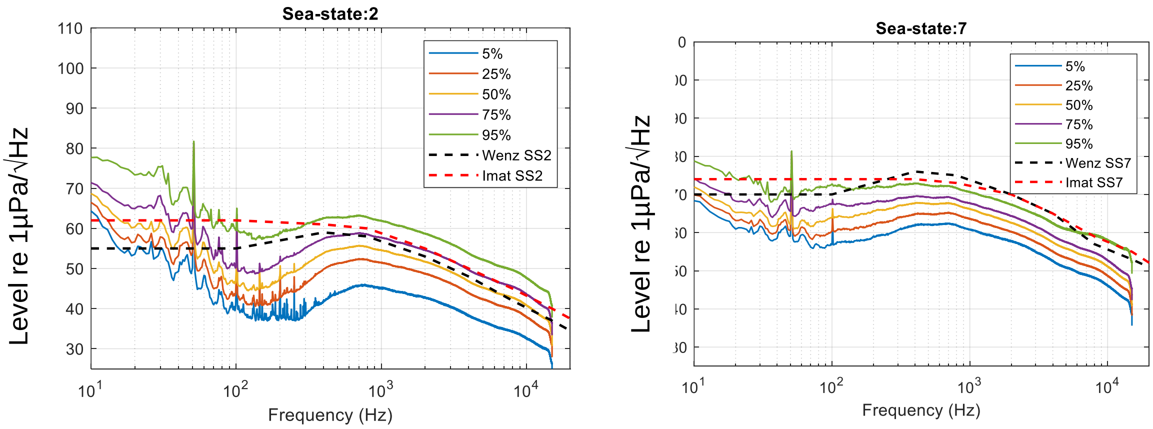

Figure 6: Percentile values of ambient noise for sea-state 2 (left) and 7 (right).

Wind Direction

At the measurement position in the archipelago, Figure 2, the wind fetch is quite different in different directions. In Figure 7 the logarithmic ($10*\log_{10}$[km]) fetch as a function of direction is plotted. The shortest fetch is in the W and NW directions (around 5 km), and the longest in the S direction (around 40 km).

If we compare the AN statistic for two different sea states and directions, we find interesting differences, Figs. 8 and 9. For the lower sea state, 1, there is little difference between the W (3 nm fetch) and S (20 nm fetch) directions. In both directions the 50:th percentiles come close to the Wenz and Imat curves, except for lower frequencies. This discrepancy is often seen in very shallow waters, usually attributed to the higher transmission loss at lower frequencies in shallow water, compared with "blue water" for which the curves are calculated.

For the higher sea state, 5, there is a distinct difference between the two directions. For the W direction the Wenz curve follows the 95:th percentile. But for the S direction, the Wenz curve is still closest to the 50:th percentile.

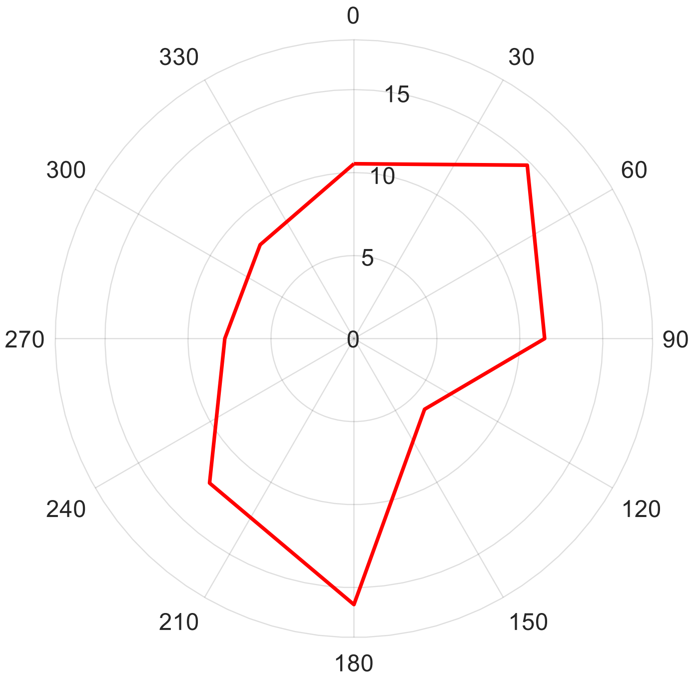

Figure 7: Logarithmic fetch distances as a function of direction (10*log$_{10}$[km])).

In general, we find that the discrepancy between the Wenz curves and the recorded AN increase for higher sea states. Also, the discrepancies are larger in directions with short fetch.

In Figure 10 a comparison is made of the sea state differences between measured AN and the Wenz curves for three different fetches. As can be seen, the AN is almost always below the Wenz values. For the longest fetch, 20 km, there is a weak dependence on sea state. But for the shortest fetch 1 km, the sea state dependence is strong.'

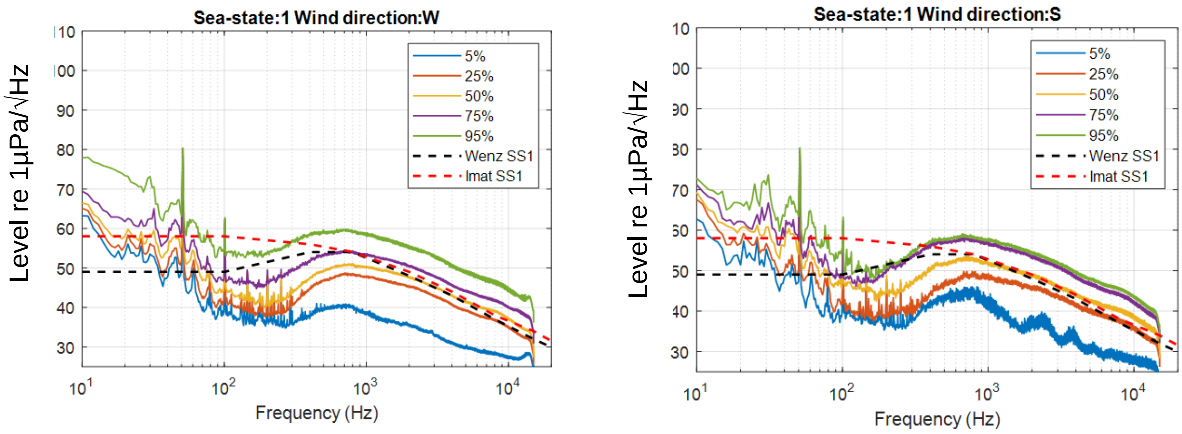

Figure 8: AN statistic for sea state 1 in the west (left) and south (right) directions

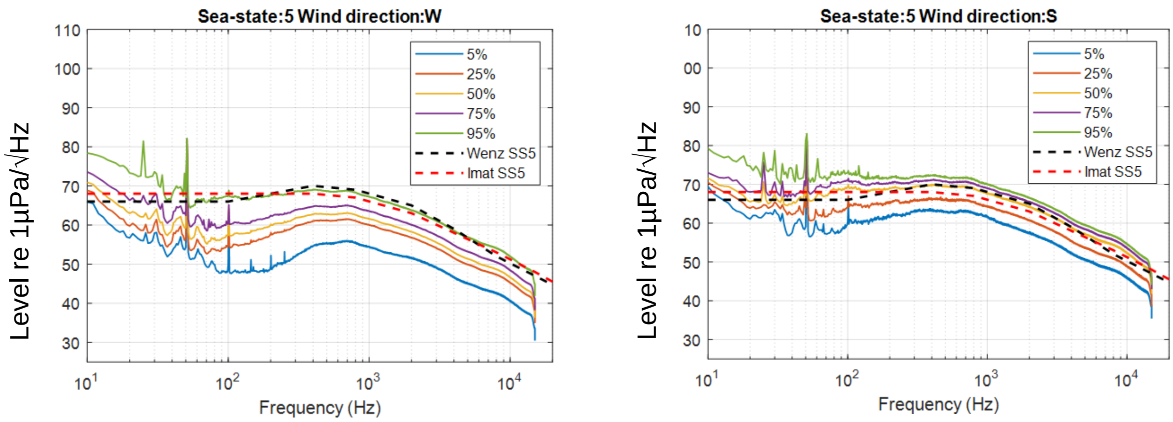

Figure 9: AN statistic for sea state 5 in the west (left) and south (right) directions.

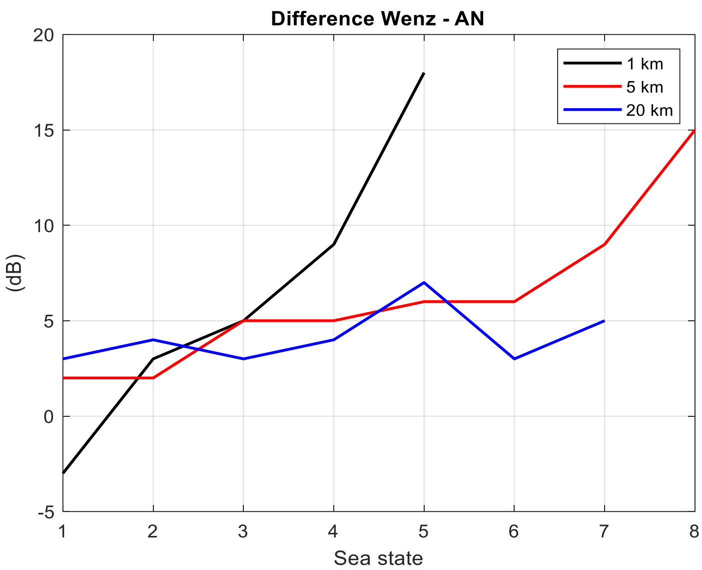

Figure 10: Difference between Wenz curves and measured AN for three different fetch distances, as a function of sea state.

Rain

Unfortunately, there was little rain during the time of the experiment. An example of the few rain cases is given in Figure 11. As can be seen, the rain lasted for less than an hour, with a strength of around 0.2 – 0.3 mm/min, i.e. fairly strong. However, there is no effect on the octave band noise levels. There is one event with a strength of 1 mm/min, at minute 11841, i.e. quite heavy rain, but not even this event can be detected in the noise levels.

Rain generated AN usually has a frequency above 1 kHz. But in the octave band levels in Figure 11 there is no frequency dependence, not even at the heavy rain event.

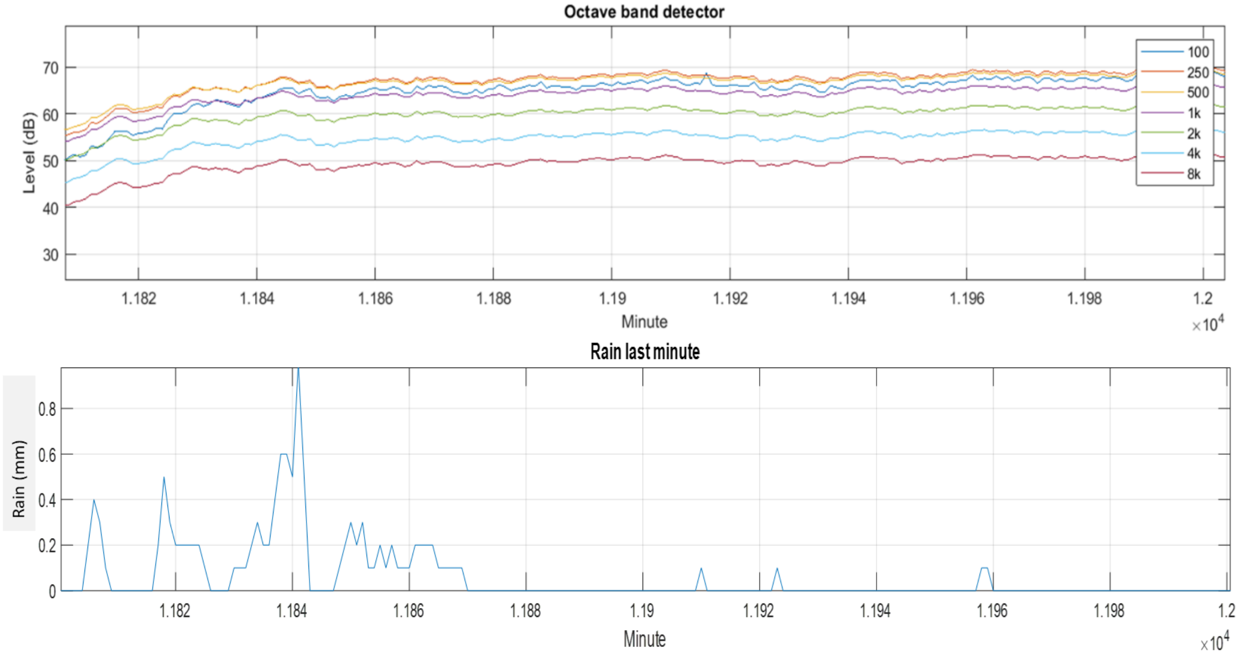

Figure 11: Octave band levels (upper part) and rain in mm/min (lower part), as a function of time.

CONCLUSIONS AND RECOMMENDATIONS

Our experiment shows that the AN in the archipelago in many cases is lower than predicted by the standard Wenz curves.

In summary, we can draw the following conclusions:

- There is a strong relation between fetch, sea state and AN.
- At higher sea states the AN is 10 dB or more below the Wenz curves.
- ASW with passive sonar in the archipelago can utilize weather conditions (i.e. wind directions), to minimize the fetch and maximize the performance.

Our recommendation is that when an ASW operation is planned, the wind forecasts should be used to find sonar positions with the shortest fetch. This will give the best performance for the passive sonar.

In this study we have expressed sea state as a function of wind speed. However, it may be more appropriate to express sea state in terms of wave height. Unfortunately, no wave rider was available in this experiment. Future measurements should include recordings of wave heights, as these may correlate better with AN than just wind speeds.

REFERENCES

1. P.C. Wille, and D. Geyer, "Measurements on the origin of the wind-dependent ambient noise variability in shallow water," *J. Acoust. Soc. Am*.**75(1)**, 73-185 (1984).
2. J. Pihl, J-O. Hegethorn, S. Ivansson, P. Moren, E. Norrbrand, B. Nilsson, G. Sundin, A. Wester, and V. Westerlin, *Underwater acoustics in the Baltic*, Swedish Defence Research Agency (FOI), report FOA-R—98-00727-409—SE (1998).
3. E. Dahlberg, R. Lennartsson, M. Levonen, L. Persson, Properties of acoustic ambient noise in the Baltic Sea, *Proc. 1st UAM,* Heraklion, (2005).
4. Ari Poikonen, thesis, Aalto University, 18 (2011). Adapted from G.M. Wenz, "Acoustic ambient noise in the ocean: Spectra and sources," J. Acoust. Soc. Am.**34(12)**,1936-1956 (1962).
5. http://www.omnitechelectronics.ca/docs/33/sensor-arrays-pass-2447v1.pdf