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THE EASTERN CANADA SHALLOW WATER AMBIENT NOISE EXPEIRMENT

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THE EASTERN CANADA SHALLOW WATER AMBIENT NOISE EXPERIMENT

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Abstract - **In recent years the underwater acoustics community has shifted focus from oceanic to littoral water areas. Working with shallow water acoustics is extremely challenging since the environment can change dramatically in both time and space. The Eastern Canada Shallow-Water Ambient-Noise (EC-SWAN) experiment had the purpose of collecting data on the temporal and spatial variation of ambient noise in Eastern Canadian waters. One hour data samples were collected monthly from four sites across the Grand Banks of Newfoundland and the Scotian Shelf from December of 1995 to December of 1996. This paper will describe the experimental process utilized, and present samples of the data that demonstrate the temporal and spatial variability observed. In particular, the variability of the noise field due to biological, shipping and wind sources is explored.**

I. INTRODUCTION

As in any signal detection application, working with sonar requires knowledge of both the signal to be detected and the background within which the signal must be detected. For sonar performance prediction (required for sonar design and for operational planning) there is a large volume of literature on the modelling of signal characteristics at the receiver. However, the background is less easily modelled since it is often spatially and temporally dependent. Thus, the background, or ambient, noise model used is generally an empirical one based on measurements taken in the environment of interest.

Spatial and temporal variability of ambient noise is dependent on the distribution of sources and the variability of the acoustic transmission loss. Both factors are known to be quite variable in littoral or continental shelf waters, therefore it is expected that ambient noise will be as well. Man-made and biological noise is increased in intensity due to the convergence of shipping routes into ports, the congregation of marine life that feeds off the nutrients found in most shallow water areas, and the inevitable presence of fishing fleets that follow the biological activity. Transmission loss also varies tremendously in shallow water as bottom effects become more important and sound-velocity profiles change due to mixing of water masses of differing salinity and temperature. Thus, in addition to variability due to physical location (bottom type, proximity to ports, etc.) there are significant temporal variations expected. Generally three temporal time scales are of interest: short term, on the order of minutes; diurnal; and, seasonal.

The Defence Research Establishment Atlantic (DREA) has an ongoing program to study ambient noise in waters of interest to the Canadian navy. While the majority of this work has in the past been on ambient noise in deep water areas, there have also been substantial efforts to examine shallow-water ambient noise [Piggott (1964), Zakarauskas (1990)]. Zakarauskas, in particular, reports on a series of experiments conducted over a 14-year period in the 1970s and 80s. However, a drawback of most of these studies was that sample periods and locations were constrained by limits on ship time and the requirements of other measurements. Thus, Zakarauskas (1990) found there were few samples on the Grand Banks, in winter or at high wind speed. In addition, few experiments had measurements taken over an extended period; the exception is Piggott's measurements which were from a shore-based array.

II. EXPERIMENTAL OBJECTIVES AND CONCEPT

The Eastern Canadian Shallow Water Ambient Noise activity was conceived with the main objective of obtaining a good understanding of the temporal and spatial variability of ambient noise in Eastern Canadian shallow water areas.

In order to fulfill this objective, ambient noise data needed to be collected from a variety of representative sites across Eastern Canadian continental shelf areas. Further, the data had to be sampled such that significant temporal changes in the noise field could be discerned. The optimal data collection system would be a set of moored sensors which are then monitored for a period of over a year. Such a system would allow for a full investigation of the ambient noise field. However, the cost of developing and maintaining such a network of sensors is prohibitive in the current economic climate. A second option would be the use of ships (research and military) of convenience, as has been done in the past. The use of this type of data collection limits the control over the data collection procedure and could entail a large administrative burden. Again the cost of ensuring a sampling sufficient to estimate the seasonal and spatial variations would be large. However, the use of ship platforms would allow a sampling of all temporal time scales. The third option examined for the program entailed the deployment of sensors from aircraft. By using long-endurance aircraft it is possible to sample the short duration temporal variations from a field of local sensors at a number of geographical locations in a single flight. Diurnal and seasonal temporal variation may be conducted by increasing the number of flights accordingly.

After examining the options and relative costs an experimental concept was developed containing the following elements:

- use of air deployed operational/production sensors;
- environmental/spatial variability to be sampled by picking a number of representative areas spread across the Eastern Canadian continental shelf;
- monthly measurements to sample seasonal variability;
- sampling of the short term temporal variability;
- sampling of the local spatial variability; and,
- sampling of the horizontal and vertical directivity of the noise field.

III. DATA COLLECTION

Data collection was conducted using twelve dedicated CP140 AURORA maritime patrol aircraft (MPA) flights by 14 Wing Greenwood in Nova Scotia from December 1995 until December 1996. Four geographic locations described in Table 1 and Fig. 1 were visited at roughly 30 day intervals to obtain one hour ambient noise samples at each site.

The four different acoustic sensors employed in the experiment are listed in Table 2. Air-deployed expendable bathythermographs (AXBT) records were used to estimate the sound-velocity profile in the water column and the aircraft radar was employed to determine shipping density in a 50-75 nautical mile radius of the site. Weather data were obtained by direct observation from the aircraft, by radio from ships in the areas, and post-flight hindcast from the Maritimes Weather Centre.

At each site sensors were placed at the apices of an equilateral triangle with 10 nautical mile sides as shown in Fig 2. This deployment pattern provides a sampling of the local spatial variability. At each apex of the triangle a primary set of sensors consisting of one 53D(2) sonobuoy, one 525 sonobuoy, and one 527 sonobuoy were deployed. This set of sensors gave some horizontal and vertical directivity at each apex. In addition the use of three sensors ensured the redundancy required to detect unserviceable buoys and/or problems with the data stream. A

Table 1 - Site descriptions

Location	Bottom	Depth	Shipping
Grand Banks	Thin sediment over hard rock	70 m	Periodic Fishing
South of Avalon Peninsula	Sand and gravel	100 m	Laurentian Channel and Fishing
Western Bank	Sable Sand [3]	70 m	Halifax, Oil Rigs and Fishing
Emerald Basin	Clay over silt [3]	200 m	Halifax and Fishing

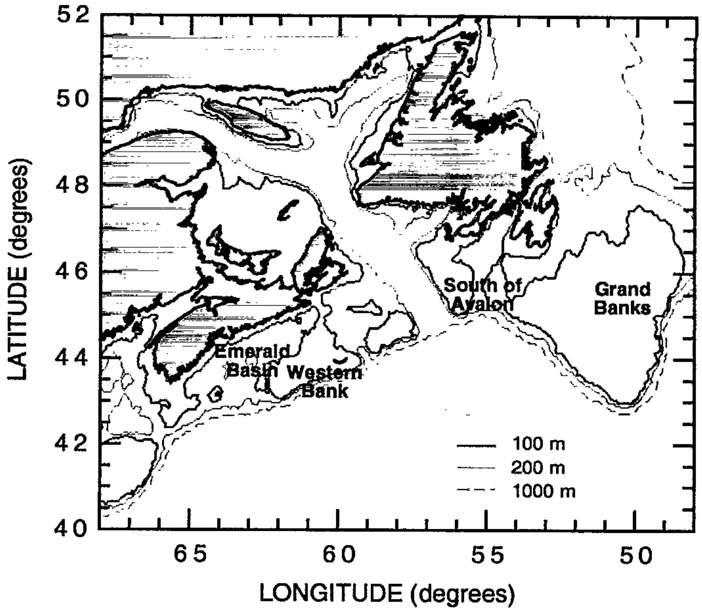

Fig. 1. Map of the eastern Canadian continental shelf giving the location of the four geographical areas sampled.

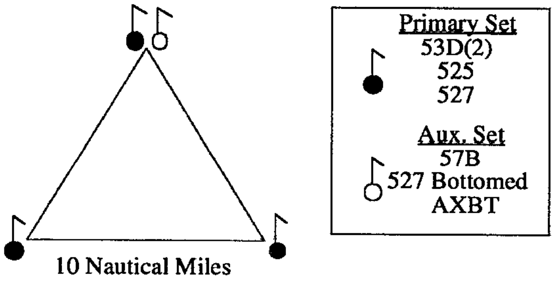

Fig 2. Local sensor deployment for each site.

Table 2 - Acoustic Sensor Description

Name	Sensor Type	Bandwidth
AQS-53D(2)	Omni & Horizontal Directivity	10-2000 Hz
AQS-525	Omni & Limited Vertical Directivity	10-2000 Hz
AQS-527	Omni	10-200 Hz
AQS-57B	Calibrated Omni	10 Hz-40 kHz

fourth set of three buoys consisting of a 527 buoy set to its maximum depth, an individually calibrated 57B sonobuoy, and an AXBT for sound-velocity profile estimation was deployed at the northern apex. All sonobuoys, except the 527 in the fourth set, were deployed to a nominal depth of 30 metres.

The 527 buoy in the fourth set was set to deploy to its maximum depth so that it would rest on the bottom. This was meant to allow the measurement of the difference in the noise field between the 30 m depth and the bottom. Unfortunately, very little quality data were obtained due to the lack of sufficient decoupling between the sensor and the deployment mechanisms.

Data collection took approximately 1.5 hours at each site, with the first half hour spent on deploying the sensors, obtaining an AXBT, determining serviceability of sensors, and replacing sensors when required. This was followed by the one hour of official recording of data.

IV DATA PROCESSING

The analog acoustic data from the sonobuoys were radio uplinked to the CP140 aircraft and written at 7.5 in./s on a 28 track magnetic tape using the onboard analog tape recorder (ATR). The data tapes were then returned to DREA for digitization and processing.

At DREA the data were read on a Honeywell 96 analog tape reader, demultiplexed (where required), and digitized on a MASSCOMP data acquisition computer using a 12 bit A/D board. The analog input stream was anti-alias filtered using a Butterworth low-pass filter with corner frequency of 2400 Hz and sampled at 6144 Hz. The digitized data streams were then recorded in a DREA multi-channel data format on 8 mm magnetic tapes.

Processing of the data occurred in two stages. First the digitized data streams were split into 300-second samples and processed using 8192 point FFTs to produce 0.75 Hz spectral estimates. The spectral estimates were then displayed in a frequency-time intensity greyscale format to assess data quality.

The most representative single buoy was chosen from each primary set of sensors. Then the 300-second samples that passed the data quality procedures were used to produce calibrated spectral samples in third-octave bands from 10 to 2000 Hz. These final spectral samples were then transferred to a set of computer spreadsheets for data analysis and presentation.

V TEMPORAL VARIABILITY

Different noise mechanisms are responsible for the noise levels across the frequency bands of interest. Shipping traffic is usually the dominant noise mechanism for frequencies between 10 and 100 Hz. Above 100-200 Hz, wind excited noise (or sea surface agitation) is usually more important. Around 20 Hz, the Scotian Shelf has an additional contribution from whales, when present. The subsequent sub-sections try to isolate the three main noise sources by looking at three separate frequency bands. Temporal variability throughout the year is investigated.

A. Whale noise (20 Hz)

The finback whales typically found on the Scotian Shelf and Grand Banks areas have strong emissions around 20 Hz [4,5]. Fig. 3 shows the 20-Hz (third-octave band) noise level as a function of flight date throughout the year, for the 4 sites. A one-year cycle is clearly evident in the data, with a noise level variation in the order of 25 dB from peak to low. From this figure, the peak whale season is defined as fall (October) to mid-winter (January).

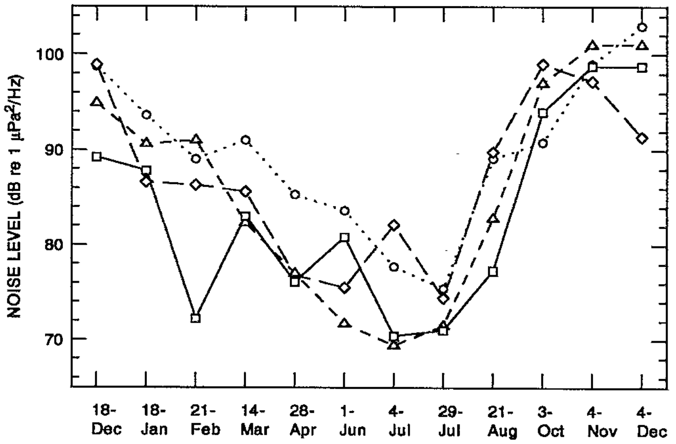

Fig. 3. Noise level at 20 Hz vs flight date (1995-1996). Solid line: Grand Banks; short-dashed line: south of Avalon; long-dashed line: Western Bank; dotted line: Emerald Basin.

B. Shipping traffic noise (63 Hz)

Fig. 4 shows the 63-Hz (third-octave band) noise level as a function of flight date throughout the year, for the 4 sites. This band was chosen because shipping noise typically peaks near this frequency. The overall noise level in this band depends on the number of ships in the area, on their respective noise levels, and on the propagation conditions.

The precise noise contribution of the ships is difficult to ascertain for two reasons. First, the propagation conditions determine how large an area we need to consider: ships in low-loss environments will be heard over greater distances. Second, the actual number of ships in the area (particularly out of the 50-75 n.mi. circular area centered on the deployment site, for which we have no shipping information) and their individual noise levels are hard to quantify.

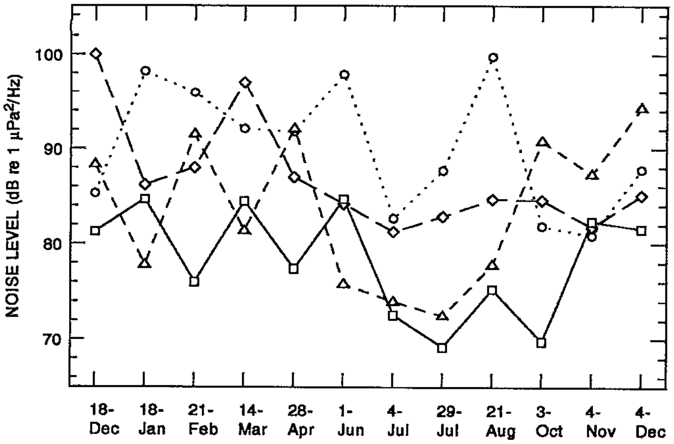

Fig. 4. Noise level at 63 Hz vs flight date (1995-1996). Solid line: Grand Banks; short-dashed line: south of Avalon; long-dashed line: Western Bank; dotted line: Emerald Basin.

Fig. 5 illustrates the temperature profile measured with AXBTs over Emerald Basin. The dark grey zone represents the range of temperatures measured in the summer months (from May to September); the light grey zone represents the temperatures measured during the other months; the medium grey zone is the overlap between the two previous zones. (The other sites have similar profiles, but the water depths are shallower.) In the summer months, the warm layer near the sea surface redirects the energy from a source near the surface towards the seabed (downward refracting profile), and the interaction with the seabed is increased. Therefore, propagation losses for shipping noise are higher in the summer, and the measured noise levels are lower. Fig. 4 demonstrates such a dip for the Grand Banks and south of Avalon sites. The dip at the two other sites is weak. This difference is due to the higher shipping noise from nearby sources at these sites due to the oil drilling platform (Western Bank) and the approaches to the Halifax harbour (Emerald Basin). The importance of nearby sources is substantiated by the high standard deviations (not illustrated here) of the noise levels at 63 Hz for these last two sites. The statistics of a nearby ship are expected to show more variation, and therefore higher standard deviations than a far-away ship. This was observed in the summer months (mostly Western Bank and Emerald Basin), when the high propagation losses reduced the contribution from far-away ships.

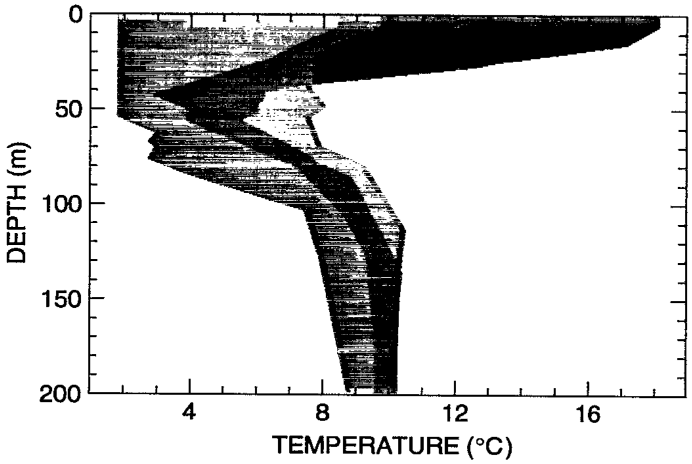

Fig. 5. Temperature profile over Emerald Basin. Dark grey zone: flights of May to September; pale grey: flights of November to April; medium grey: overlap of two previous zones.

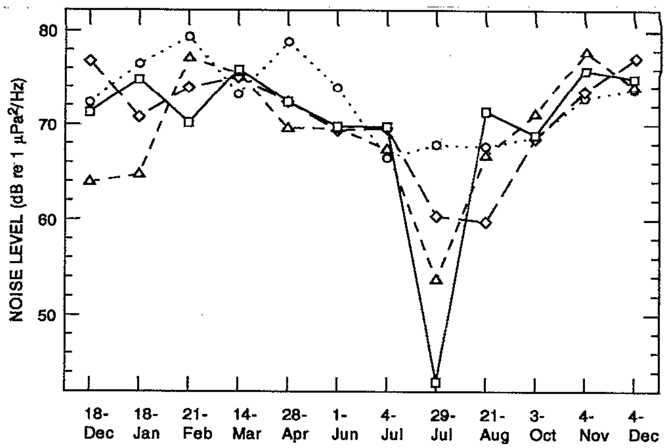

Fig. 6. Noise level at 500 Hz vs flight date (1995-1996). Solid line: Grand Banks; short-dashed line: south of Avalon; long-dashed line: Western Bank; dotted line: Emerald Basin.

C. Wind generated noise (500 Hz)

Fig. 6 shows the 500-Hz (third-octave band) noise level as a function of flight date throughout the year, for the 4 sites. Wind generated noise is usually dominant in this band, although shipping noise can still be important, especially if the wind speed and sea state are very low.

The seasonal dependency of the noise levels in Fig. 6 is affected by the strong dependency on wind speed, which varied greatly from month to month at each site. Even though a summer dip, similar to that in Fig. 4 (shipping traffic frequency), is observed in Fig. 6, it should be noted that the measured winds (not shown here) were on average slightly lower in the summer time. The very low levels on 29 July are due to exceptionally low winds on that date. The Weather Centre reported winds of 5 kn at Grand Banks and south of Avalon, and 10 kn at the two other sites, with sea state of 1 at all sites. However, the aircraft crew reported a glass-like surface for the first two sites, leading us to believe that the winds were even lower than estimated by the Weather Centre.

The noise level (L) as a function of wind speed (from 500 Hz to 2000 Hz) were modelled using the Merklinger and Stockhausen model [6]:

$$L = \left\{ \left(L_0 + 5\log\left[\frac{f}{770 - 100\log V}\right]\right)^{-25} + \left(L_0 + 17\log\left[\frac{f}{770 - 100\log V}\right]\right)^{-25} \right\}^{-1/25} \qquad (1)$$

where f is the frequency (Hz), V is the wind speed (knots) and

$$L_0 = 45 + 20\log V - 17\log\left(\frac{770 - 100\log V}{770}\right). \qquad (2)$$

The constant 45 in (2) replaces the 42 used by Wenz for deep water [7]. The higher value for shallow water was introduced by Piggott [1].

An example of the model fit is shown in Fig. 7 for the Grand Banks site. The low data point at 5 kn represents the very calm day on 29 July. The model results over all sites fit the data reasonably well for wind speeds higher than 10 kn. However, at lower wind speeds, the contribution from shipping noise increased the measured noise levels, and deteriorated the fit with the model. This effect was progressively stronger from 2000 Hz to 500 Hz, i.e. the contribution from shipping traffic was most important at the low end of the frequency band of interest (500-2000 Hz).

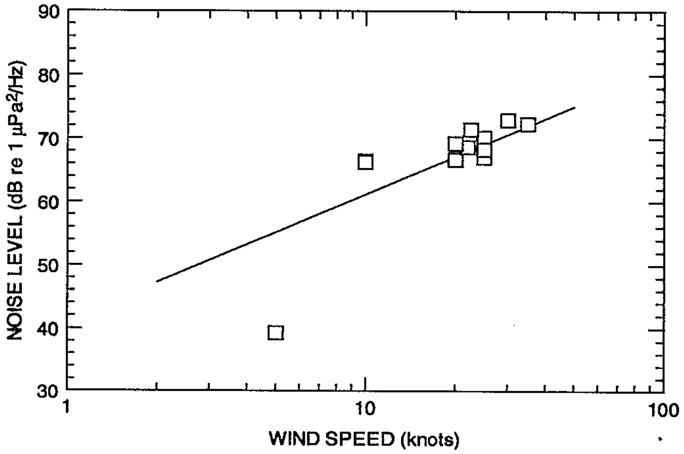

Fig. 7. Measured ambient noise level at 1260 Hz (1 representative datum per month) vs wind speed over Grand Banks (squares) and modelled results from (1) (solid line).

VI SPATIAL VARIABILITY

The spatial variability can be looked at in two different ways. First, a variability with site, due to the different seabeds can be looked for. Second, spatial fluctuations within the sites themselves might also be observed. These two effects are discussed next.

A. Site dependence

The site dependence is introduced primarily through seabed variations, and through external factors like major shipping lanes or climatic tendencies if any. For a given frequency, the variation is noticeable if the contribution of the main noise source at that frequency is the same for each site; this condition is rarely met.

Very little difference between sites is seen at 20 Hz (Fig. 3). We can exclude the whale effect by comparing the sites at the time of year when the whale noise is minimum (July). A small difference is observed, the noise levels over the soft seabed sites (Emerald Basin and Western Bank) being higher than those over the hard seabed sites (Grand Banks and south of Avalon), implying that the propagation losses at 20 Hz are higher at the eastern sites. This higher loss was expected over Grand Banks where the seabed is a thin sediment layer over hard rock (see Table 1). Large propagation losses at 20 Hz were measured over a similar Continental Shelf site due to shear-wave resonances within the sediment layer [8].

The tendency is the same at 63 Hz, however the differences observed between the sites are due to the shipping distribution. The Grand Banks and south of Avalon sites are relatively free of ships, while the Western Bank site is near an oil drilling platform (with associated shipping traffic), and the Emerald Basin site is nearer the coast and the shipping lanes heading for the port of Halifax.

At higher frequencies, the wind dependence is stronger than seabed effects, and hides a potential site dependence. However, when wind speeds are extremely low (29 July in Fig. 6), we can hypothesize on a seabed effect. For example, the propagation losses are probably higher on the Grand Banks (solid line) than south of Avalon (short-dashed line), since the noise levels are so low over Grand Banks. We should be careful, however, before concluding similarly for the two other sites, as the higher shipping noise might be contaminating the noise levels at that frequency.

B. Spatial fluctuations

Spatial fluctuations at each site were investigated by comparing for each site the standard deviations (not shown here) of the noise levels at each of the three deployment apices (see Fig. 2). The following observations were made:

- At high frequency (above 500 Hz), the standard deviations were generally low (below 2 dB) at all sites. On a few occasions, the deviations were larger, and explained by differences in wind speeds between apices, or by different contributions from shipping traffic at each apex (when the wind speeds were low).

- At shipping frequencies (10-100 Hz), the standard deviations were higher (up to 3-4 dB), indicating that shipping traffic introduces more spatial variability than wind speed.

- At 20 Hz, the standard deviations were highest on the Grand Banks (7-8 dB), where presumably the whales are present more often over one apex than the others. At the other sites, the deviations at 20 Hz are generally below 3-4 dB.

VII CONCLUDING REMARKS

The use of operational acoustic sensors and Maritime Patrol Aircraft for deployment and monitoring was an effective and efficient method for collecting ambient noise data.

A vast set of ambient noise data was collected over the one-year period at four shallow-water sites on the Scotian Shelf and Grand Banks. The data were collected with air-deployed sensors, which proved to be reliable. This ensured data redundancy for each deployment, and confirmed the good data quality. The data cover a wide range of environmental conditions, in terms of wind speed, sea temperature profile, shipping traffic and whale distribution.

A strong yearly cycle was noted in the 20 Hz data, following the whale migrations in the area. The peak whale season (September to January) was clearly defined.

Variations in shipping traffic were noted across the sites. High noise levels were seen at Western Bank due to the oil rig platform, and at Emerald Basin due to the shipping lanes converging on Halifax. The large area covering Grand Banks and the area south of the Avalon Peninsula were comparatively quieter at shipping frequencies.

The noise levels as a function of wind fit the Merklinger-Stockhausen model for wind speeds above 10 knots. Below 10 knots, the modelling was not as successful, especially for frequencies at the lower end of the 500-2000 Hz band, presumably due to of shipping noise affecting these frequencies.

No strong conclusion was drawn on site dependence of the noise levels (i.e. variations with seabed), due to the stronger influence of wind speed and shipping traffic.

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