UNDERWATER AMBIENT NOISE (0.05 - 63 kHz) SPECTRAL DISTRIBUTION IN AN ALASKAN FJORD OVER TWO YEARS

M. P. Schilt
Naval Surface Warfare Center
Carderock Division, Detachment Puget Sound
Bremerton, WA 98314-5215

J. D. Elterich
Naval Surface Warfare Center
Carderock Division, Detachment Puget Sound
Bremerton, WA 98314-5215

I. INTRODUCTION

Abstract - The Carderock Division, Naval Surface Warfare Center (CDNSWC), Detachment Puget Sound, deployed an autonomous MINIMET buoy in Behm Canal, Alaska from July 1989 through May 1991 to collect acoustic and meteorological data. The data were acquired to support advanced design efforts for acoustic measurement systems in preparation for the establishment of the Southeast Alaska Acoustic Measurement Facility, (SEAFAC).

The Behm Canal site, a glaciated fjord, represents a fairly deep embayment (400m) with a soft bottom (porosity of about 0.8). Data were gathered over a wide range of wind speeds (0 - 21 m/s) and during periods of rain and snow.

The hydrophone array and electromagnetic current meter were taut bottom-moored to a sub-surface buoy. The MINIMET buoy with meteorological sensors to measure wind, air temperature and sea surface temperature was slack-moored to the sub-surface buoy. Each hour the buoy acquired and analyzed ambient noise data. The data were processed and compressed into the 32 byte ARGOS transmission format and then transmitted via the ARGOS satellite. The hourly one-third octave data (32 bands) were available via phone lines. Four Digital Acoustic Tape (DAT) cassette recorders were also contained within the buoy to permit more detailed off-line narrow band analysis, albeit on a less frequent sampling basis (roughly every four hours).

Many ambient noise data bases exist that are relatively limited in duration of measurements (i.e., 2 - 3 weeks to a few months). In addition, nearly all have separation (usually between 5-20 nautical miles) between the underwater ambient measurement site and the meteorological measurement site. Also, few are oceanic shallow water, which of late has developed heightened interest.

Measurements were made in Behm Canal, Alaska in 1989 to characterize the ambient noise field and establish correlation between the noise levels and local weather conditions [1]. However, these manned, on-site, ambient noise measurements rapidly became cost prohibitive necessitating the design and deployment of an autonomous system.

A MINIMET buoy system was deployed 13 July 1989 and remaind in service until 05 May 1991 with a total of approximately 8,500 samples acquired over the two year period.

This paper describes the test, the MINIMET system, subsequent data processing, and discusses the measured data. The results of the relationship between noise level and wind speed, rain, and temperature are compared to other results reported in the referenced literature.

II. TEST DESCRIPTION

The measurements were made in the western arm of Behm Canal, Alaska, at a location near Ketchikan as shown in Fig. 1. This site represents a fairly wide and deep fjord with a water depth of about 400m in the general vicinity of the measurement location. Core samples of the upper few feet of the seabed have shown the sediment to be a very fine organic clay or clay/silt with a typical median grain size
of 0.01 mm [2]. This implies that the bottom is quite soft [3] and has a high associated bottom bounce loss (e.g., losses are greater than 20 dB at angles above 10° and frequencies above 10 kHz based on grain size alone [4]). The sediment layering to basement rock is fairly thick, with thickness values ranging between 15 m and 60 m surrounding the measurement site [5]. This site was nearly ideal for measuring noise generated at the sea surface by wind or precipitation, even down to 100 Hz, since man-made and biological noise sources were absent except for the occasional distant passing fishing vessel.

Fig. 2 shows the MINIMET autonomous system developed to measure ambient underwater acoustic, oceanographic, and meteorological data for automatic, unattended, long-term environmental characterization [6].

A MINIMET buoy with meteorological sensors to measure wind (anemometer height = 3.5 meters), air temperature and sea surface temperature was slack-moored to a taut moored hydrophone array and electromagnetic current meter as shown in Fig. 3.

Fig. 4 is a block diagram of the system electronics and is described in more detail in [6]. Hourly measurements included ambient acoustic levels based on standard one-third octave bands from 50 Hz through 63 kHz. In addition, the system has an onboard capability via CPU control to record 8 hours of hydrophone signals using Digital Audio Tape (DAT) recorders. The excellent dynamic range and frequency coverage of DAT technology extends the low frequency measurement capability and allows a more
detailed though less frequent examination of the ambient noise.

Each hourly data set were processed and compressed into the 32 byte ARGOS satellite transmission format, making hourly data available via a local phone call.

An advantage of this system was the accessibility to the data between 2 and 72 hours after acquisition. Also significant was its relative low operational expense ($15K/yr) when compared to the costs of a manned data acquisition test.

Also during the period 1984-1991, CTD measurements were obtained at the same location to determine the sound-speed profiles. Typical profiles from these CTD measurements for each of the four seasons are shown in Fig. 5. The profiles reveal moderate downbending in the summer to strong upbending in the winter.

### III. TEST RESULTS

Table I presents a synopsis of the weather and oceanographic conditions for the duration of the test conducted at Behm Canal. A wide range of conditions were encountered.

A frequency of 5 kHz was chosen to examine the variation with wind and other environmental conditions, since this frequency is high enough to avoid contamination by boat noise yet low enough to minimize the direct influence of near-surface bubbles, rain, and snow. Fig. 6 shows the one-third octave level at 5 kHz versus air temperature for different wind speeds.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>8,500</td>
</tr>
<tr>
<td>Wind speed range</td>
<td>0 - 20 m/s</td>
</tr>
<tr>
<td>Precipitation</td>
<td>834 measurements</td>
</tr>
<tr>
<td>Sound-speed profile</td>
<td>strong upbending to moderate downbending</td>
</tr>
<tr>
<td>Sea surface temperature</td>
<td>1°C - 22°C</td>
</tr>
<tr>
<td>Air temperature</td>
<td>-1°C - 25°C</td>
</tr>
</tbody>
</table>

![Fig. 4. Block diagram of system electronics.](image)

![Fig. 5. Range in SVP's at SEAFAC, 1984-1991.](image)

![Fig. 6. SEAFAC 5 kHz ambient omni-noise levels versus temperature for wind speeds of 0-10 m/s.](image)
A previous limited data set showed a significant reduction in wind-generated spectrum levels due to freezing or below freezing temperatures [1]. However, the results of the MINIMET comprehensive two year data set (Fig. 6), does not show a discernable trend for the one-third octave levels obtained at 0°C versus the levels obtained at 18°C. This is particularly true for the measurements at wind speeds greater than 3 m/s where the spectrum level becomes highly correlated with the wind speed.

The data base was grouped by wind speed and the mean acoustic level measured in each one-third octave band. The results for the 5 kHz one-third octave band are presented in Fig. 7.

The Knudsen curves [7] are overlaid along with the number of samples obtained at each wind speed annotated. Note that the SEAFAC measured data mean falls below the Knudsen level at wind speeds up to sea state 2-3 or 5 m/s. As the wind speed increases above 5 m/s, the SEAFAC measured mean levels are higher than the Knudsen levels. This may be due to the close proximity of the measurement site to the shore. The breaking waves on shore, side wall and bottom reflections may contribute to increasing the isotropic and horizontal components of the noise field over that of an open ocean site.

Several examples of averaged rain noise spectra acquired at SEAFAC with wind speeds ranging from 0 to 5 m/s are shown in Fig. 8. Most notable in these spectra, compared with the wind noise spectra, is the very pronounced rounded peak centered at approximately 16 kHz or 20 kHz depending on the wind speed. For wind speeds equal to or less than 2 m/s, the rain peak occurred at 16 kHz. At wind speeds greater than 2 m/s, the rain peak occurred at 20 kHz. Recent measurements taken in the open ocean [8] are consistent with the Behm Canal spectra in the vicinity of the peak. For these rain noise measurements, rain rate data were not obtained.

Fig. 9 presents the general spectral shape of light, moderate and heavy wind induced spectrums. These spectral shapes confirm the observation [1] that the wind noise spectra begins rising above Knudsen/Wenz at about 10 kHz. The humps may be described as a series of spectral peaks [9].

Fig. 10 shows the 5 kHz monthly average spectral variation and its comparison with wind speed over the two year period. Occasionally, equipment malfunctioned causing some gaps in the data.
Fig. 10. SEAFAC: 5 kHz average ambient omni-noise level and wind speed by month from July, 1989 to May 1991.

Other spectral observations noted include:

1) The 5 kHz averages varied from 1 dB to 7 dB from month to month.

2) The 5 kHz diurnal variation was approximately 4 dB.

3) The 5 kHz average variation from year to year of any specific month was negligible.

IV. SUMMARY

An autonomous system was developed and used to environmentally characterize an Alaskan fjord. The system acquired ambient underwater noise from 50 Hz to 63 kHz, in situ wind speed and direction, air and sea surface temperature and current flow and direction at the hydrophones. The data from the remote site were inexpensively transmitted by satellite and received in Bremerton, WA.

The ambient noise measurements acquired at SEAFAC are unique in several ways. A broad frequency range is covered, extending out to 63 kHz, where thermal noise effects become measurable. Meteorological data is measured concurrently directly over the measurement site at a standard reference height of 3.5 meters. Air or sea surface temperature did not have a discernable effect on the measured spectrum. In this relatively shallow, fjord-like basin ambient levels for wind speeds less than 5 m/s are less than the reference Knudsen curves. On the other hand, as the wind speed passes 5 m/s the ambient levels increase with increasing wind speed above the reference curves.

Rain noise spectra compared favorably with open ocean measurements in the vicinity of the peak (16 kHz to 20 kHz depending upon wind speed). Analysis of the data confirmed that increasing wind speed shifts the rain peak upwards in frequency to 20 kHz.

ACKNOWLEDGEMENTS

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REFERENCES