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2pUWb4. Arctic ambient noise measurements in support of the Northern Watch Project  
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During August 2012, acoustic recording systems were deployed in Barrow Strait as part of the Defence Research and Development Canada (DRDC) Northern Watch Technology Demonstration Project. Two Starfish Sensor Cubes each with a 1-m cube of seven hydrophones operating in the frequency range of 5 - 750 Hz, and two single-hydrophone, Autonomous Multichannel Acoustic Recorders (AMAR) providing a 30-kHz signal bandwidth were deployed. The Starfish were deployed for two one-week intervals. One AMAR was deployed for two weeks partially overlapping the Starfish deployment. The second AMAR was deployed for a period of one year with recovery planned for August 2013. The observed underwater noise picture is one of high variability ranging from an extremely quiet to a noisy environment. Noise sources included: A 500-m long iceberg grounded within 500 m of one of the Starfish; a large ice island (4-5 km$^2$) that passed within 4 km of the sensors; a small number of motoring vessels; significant wind events that caused rapid and strong variations in the noise field; and a small number of marine mammal detections. After our departure, a large number of Beluga whales were observed visually. The remaining AMAR may detect these late summer visitors.

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INTRODUCTION

This paper presents the preliminary analysis of underwater ambient noise recorded along the north shore of Barrow Strait at Devon Island, Nunavut, Canada. Two acoustic sensors were used: a JASCO Applied Sciences Canada Autonomous Multi-Channel Acoustic Recorder (AMAR) and the DRDC Starfish Sensor Cube (SSC).

The acoustic data presented here were collected with the AMAR for a two-week period in August 2012 and with the SSC for a 5-day interval within the AMAR recording period. The data from the AMAR cover a bandwidth from roughly 10 Hz to 30 kHz, while the SSC data cover the band from 5 Hz to 750 Hz.

Ice cover in the region varied from 5/10 to 0/10 during the collection period. A large iceberg was grounded in the vicinity of the sensors (5.5 km to the AMAR and 0.5 km to Starfish) and remained essentially stationary during the observations. During the first four days of recording a large ice island, approximately 4–5 km² with a freeboard of about 30 m, drifted back and forward past the sensors with a minimum range of 4 km. Both the ice island and iceberg are fragments of a much larger piece of ice that broke free from the Petermann Glacier in Greenland in 2009. Wind speeds varied during the recording period with hourly mean speeds from 0 to 17.4 m/s (33.8 kts). Several periods of precipitation were recorded, but these were generally only very low-rate rainfall events.

THE SENSORS

The JASCO AMAR (A1) is a highly capable acoustic recording device with non-volatile solid-state memory. Up to 1.79 TB of memory is available in the current devices. The AMAR was configured with a single Geospectrum M8E amplified, calibrated hydrophone with -164 dBV/μPa sensitivity. A Sigma-Delta A/D with an effective 64 kHz sampling rate provides a useful bandwidth of 10–30,000 Hz. The AMAR was deployed at 74.61656° N, 91.50793° W at 1843 UTC on 1 August. It was recovered at 1540 UTC on 15 August.

The SSC (S3) includes a 7-element, triple orthogonal, crossed-dipole acoustic array with a centre hydrophone. The hydrophones were built at DRDC and are 2.54 cm diameter cylindrical ceramics with hemi-spherical endcaps. Each hydrophone is calibrated in the DRDC calibration facilities and has a nominal -192 dBV/μPa sensitivity. Various gain levels are available to be applied to the signal as required. A nominal gain of 70 dB was used for the S3 data set; however, the SSC has prewhitening, low-pass, and high-pass filters, that result in overall gain being a function of frequency. The SSC samples the sensors at 2500 Hz using synchronized 16-bit A/D’s at each hydrophone. The system provides a bandwidth of 5–750 Hz. Only data from the centre hydrophone of the 7-element acoustic array are included in this report. The Starfish cube S3A was deployed at 74.62718 N, 91.34098 W from 2034 UTC on 2 August to approximately 1327 UTC on 7 August with continuous recording during the period.

THE EXPERIMENTAL LOCATION

Figure 1 shows a map of the experiment area. A RADARSAT-2 satellite image is overlayed to show the actual position of the large (500-m long) iceberg that was grounded in the immediate area during the entire recording interval. The AMAR position is denoted by the label ‘A1’. The label ‘A2’ refers to the location of a second AMAR that remains deployed at this time and is scheduled for recovery during summer 2013. The label ‘S3A’ refers to the first Starfish deployment whose preliminary data analyses are included in this paper. The labels ‘S2B’ and ‘S3B’ refer to the locations where the same Starfish and a second unit (S2) were later deployed.
The 500-m long grounded iceberg is clearly visible in the satellite image. The iceberg is approximately 900 m from the nearest point of shoreline at Cape Ricketts. The water at this location is approximately 120 m deep.

The DRDC research vessel Candian Forces Auxiliary Vessel QUEST participated in the trial. This ship was used to deploy and recover the AMAR and SSC sensors. QUEST is a purpose built acoustic research vessel. It is unusually quiet and although the QUEST was detected from time-to-time it is not a dominant component of the acoustic record. Whenever possible, the QUEST was anchored in Gascoyne Inlet to minimize acoustic signals from the vessel.

The Overall Noise Picture

The lower portion of Figure 2 shows a frequency-time-intensity image (or sonogram) of the two-week period of acoustic data recording from AMAR A1. The upper portion of this figure shows the Sound Pressure Level (SPL) in the bands 10–32,000 Hz, 10–100 Hz, 100–1000 Hz, 1000–10,000 Hz, and 10,000–32,000 Hz.

The dominant factor in noise production appears to be the wind. Figure 3 shows the hourly averaged wind speed measured at the Gascoyne Inlet Camp. The camp is somewhat sheltered by the surrounding hills, but has the advantage of providing a continuous record from a stationary Vaisala wind sensor. When the wind speed increases, the noise level increases right across the 32 kHz band shown in the figure. The underwater noise and wind speed were observed to change together rapidly. In one example, winds dropped from 15.5 m/s to 1 m/s in the space of minutes. The acoustic levels immediately followed with a 15 dB decrease across most of the band.

The noise levels are roughly proportional to the wind speed throughout the recording period. There is no obvious change in the omnidirectional noise measurements over the observation period, except that the levels were lower in the middle of the period than at either the start or end. As it happens, the strongest winds occurred during 4–5 August when the ice island was moving past the receiver (probably because of the wind). The wind noise may have helped to obscure the noise contribution from the ice island.

Thanks to the DFO Real-Time Arctic Ocean Observatory [1], a historical record of hydrostatic pressure variations on a nearby moored sensor is available. These pressure
Figure 2: An overview of the acoustic environment as produced from AMAR A1 during the two-week recording interval. The upper portion of the figure shows the band-filtered SPL, while the lower portion shows the sonagram.

Figure 3: Hourly averaged wind speed measured at the Gascoyne Inlet camp.
variations are the result of the combined influence of ocean depth due to the tides and the influence of the tidal currents on the mooring, which cause small depth variations of the sensor. This latter effect dominates. These pressure time-series data (sampled every 2 hours) can be spectrally analyzed to reveal the periods of the main tidal flow components in the region.

A 2048-hour long record of data from August through to late October 2011 was Fourier analyzed to determine the apparent tidal periods since data for the deployment period are not available. The semi-diurnal period determined from this analysis dominates, as expected, with a 12.4–12.5 hour period. The diurnal period determined by these results is roughly 24.3 hours. Hamilton [2] found a period of 24.9 hours from a thorough analysis of moored sensor data.

There is a series of approximately 5-hour long impulsive bursts of noise below 100 Hz present in the sonagram. The spacing of the stronger bursts agrees well with the measured diurnal tidal period. Spacings between the weaker bursts also reveals the slightly longer than 12-hour period for the semi-diurnal cycle. It is concluded that these bursts are unwanted tidal flow induced signals on the AMAR receiver, which was deployed without a flow shield and on a buoyant bottom-mooring allowing movement in a current flow.

Several events that appear to be precipitation are seen in Figure 2. These events occur at a frequency of 13.5 kHz and upward on the 8, 9, and 10 August. Maximum amplitude occurs between 14 and 15 kHz, with a slow decrease in level at higher frequencies. Figure 4 shows a close up view of the precipitation at 1620 UTC on 8 August. There is a sharp lower frequency limit with an extended roll-off in intensity at the higher frequencies. The rainfall rate appears to increase and decrease several times. Similar characteristic rain noise was observed by Ma et al. [3] and is very different from the noise produced when rain rates are heavier.

The omnidirectional SPL shown in Figure 2 reveals very little signal contribution from ice. The most easily identified contribution of ice to the underwater sound is the occasional impulsive event associated with the breaking of ice and the resulting crash of a fragment into the sea. The larger, and longer, of these events appear as broadband pulses and in the highly compressed sonagram and are hard to distinguish from ship passages. Frequently, calving ice events produce a strong low-frequency contribution, while passing vessels generally do not. Distributed fractional ice cover does produce some sound by bumping and rubbing, but in general this is a low level source and there is no obvious record in the figure [4]. Despite the loud airborne noise audible from the grounded iceberg there is no readily identifiable signature in the figure that can be associated with the iceberg. The same can be said for the oscillating passage of the large ice island. The ice island was at its closest and most active from 3–5 August, but there is no clearly definable signal in the figure that can be associated with the ice island.

The man-made sounds in Figure 2 are mostly due to the passage of vessels, including
QUEST, which was active in the area and generally passed in the vicinity of A1 twice daily. A number of the yellow vertical stripes (in the 90 dB range) are due to the passage of QUEST, often at ranges less than 2 km. An unknown vessel passed by at 1250 UTC on 10 August.

A few of the vertical bars do not appear to be related to vessels. Some may be due to the larger ice calving events. Only the events that make noise over a longer than normal duration tend to show in the highly compressed sonagram.

In addition to the machinery noise from QUEST, a few technical equipment noise signals are captured in the sonagram. In particular, near 1600 UTC on 3 August there is an indication of the Teledyne/Benthos acoustic modem network transmissions that controlled the SSC in the band 9–14 kHz. Between 1300-2100 UTC on 5 August, a series of faint dots at 400 Hz are the result of a series of projector signals used in a transmission loss experiment.

Several motoring sailboats produce a visible record in the sonagram. These are most easily seen during the early hours of 7 August and near mid-day on 12 August. In both events, the signals are faint, but most detectable in the band 50–300 Hz and appear as a series of related tonal signals. Several other tonal signals are observed throughout the recording period, but their cause remains unknown.

Animal sounds were heard infrequently in the record. Their signals do not show up readily in the high compressed sonagram because they are too short and infrequent to dominate in the average spectral results.

**Figure 5:** An overview of the acoustic environment as produced from Starfish S3 during the five-day recording interval.

Figure 5 is a sonagram for the data recorded by the SSC. The figure shows a similar content to that shown in Figure 2. The wind noise variations are clearly visible. The resulting noise levels vary more than 30 dB over a wide range of frequencies during the recording interval. As with the AMAR, the ice related noise is not obvious in this figure. A few wideband pulses with low-frequency content are likely due to the capture of sound from larger ice calving events. QUEST avoided the vicinity of S3 for the most part and there is only one broadband signal likely due to the ship. Projector signals are clearly visible as dots in the sonagram.

The S3 sonagram is less affected by flow than the AMAR. The rigid, near bottom, position of the hydrophones is less susceptible to motion induced signals caused by currents in the water.
The cause of a wandering tonal-like signal near 28 Hz is of an unknown cause. The AMAR also captured this signal. It is possibly associated with the iceberg as noted in the next section.

The strong, broadband, modulated events visible in the sonagram record throughout the recording are due to overloads caused by the local underwater modem attached to the SSC. This modem was located less than a meter from many of the hydrophones. This was done to simplify the deployment, but was a poor decision in retrospect. Normally, the modem is buoyed up above the cube by a float. By increasing the modem-hydrophone separation to 15 m this overloading problem is easily avoided.

**Noise Levels**

Perhaps the most important result of this paper is provided in Figure 6. This figure shows the spectrum levels (1 Hz band) and their statistical fluctuations observed over the entire period (computed from one minute average spectra—65536 point FFT, 64000 real data points, 32000 point advance, hamming window, 120 averages). The lower portion of the figure shows the median spectrum and a selected number of spectra with given probabilities of being exceeded (i.e., the percentiles 5, 25, 50, 75, and 95). The upper portion of the figure shows the distribution of 1/3-octave band RMS SPLs. The median SPL is shown as a dot. A thick band above and below the dot represents the 25th and 75th percentiles (i.e., the noise will be in this range 50% of the time). The line above and below the dots represents the maximum and minimum one-minute RMS SPL observed in each 1/3-octave band. The red curve shows the root-mean-square (RMS) average spectrum level.

**FIGURE 6:** Sound pressure levels and percentile levels for the entire AMAR deployment period.
Much of the ambient noise spectrum is observed to have fairly constant levels at each frequency. Above 100 Hz the 25\textsuperscript{th} and 75\textsuperscript{th} percentiles are generally less than 10 dB apart in level. The frequencies below 100 Hz show larger variations, but this is due to the flow-induced noise on the AMAR.

The observed ambient noise falls within the Wenz limits for prevailing ambient noise in the deep ocean [5]. These limits correspond to the minimum and maximum spectrum levels observed from natural sources, excluding discrete animal calls. The median noise spectrum near Gascoyne Inlet for the observation period lays somewhere between the levels typically seen for a deep ocean sea state 1 and 2.

Although the low-frequency levels are biased by the flow-induced noise in the AMAR A1 data, the quietest observed levels indicate a very low noise, low-frequency environment occurs at least 25\% of the time. Wind noise and shipping are generally the contributing factors in the deep ocean for this frequency regime below 100 Hz.

There is a persistent and unknown source of noise near 28 Hz (see comments below) and a complex high-frequency wideband signal that is associated with precipitation.

Figure 7 shows the average spectrum for the entire S3 data set excluding the modem transmission events. The SSC provides a better estimate of ambient noise levels below 100 Hz than does the AMAR due to the reduced influence of flow noise. Overall, the levels of noise are noticeably higher for S3 than for A1. It is suggested that this higher noise level is likely due to the proximity of the grounded iceberg, which is a known source of wideband noise. Noise at S3 is generally similar or louder than the 5\textsuperscript{th} percentile of the noise intensity at A1.

\textbf{FIGURE 7:} Sound pressure levels for the entire S3 deployment period excluding the modem transmission events.

The tonal at 400 Hz is due to our projector signals used for transmission loss experiments.

The cause of the wandering frequency signal near 28 Hz is unidentified as of yet, but it appears to be independent of ice cover and the presence of vessels. It was observed in both the AMAR and SSC data. It may be associated with the grounded iceberg as it is the only potential source of noise constantly present. The signal is stronger in the SSC data than in the AMAR data and this is another indication that the iceberg may be the source of the signal. ‘Singing Icebergs’ have been reported previously [6], but the nature of the signal and durations described is different from what we have observed. The tonal frequency we observed shows evidence of a repeatable daily peak in frequency, which may be related to tidal flows. There is also a visual correlation with frequency and wind speed. In this Arctic environment, tides, winds, and noise are all correlated to some degree. The result is a complex variation in the unidentified signal frequency, which requires further study. Future work will examine the signal's level and
frequency over time and correlate with both tide and wind. We will also attempt to estimate the
direction of the source of the signal from the Starfish data and will also compare the signal in
the S3B and S2B data records.

CONCLUSIONS

This paper provides information on the ambient noise levels near the north shore of Barrow
Strait observed during a two-week interval in the summer of 2012. Variable wind and ice
conditions were observed during this interval and it has been determined that wind is the major
factor determining the underwater noise levels at all frequencies within our 30 kHz bandwidth
of observation.

The noise associated with the drifting ice island is not clearly apparent in either the AMAR
or SSC omnidirectional data, as the noise of the ice is dominated by that due to wind.
Precipitation is a dominant source of high frequency noise.

Future analysis will make use of the data from the other Starfish deployments and the
directional capabilities of the SSC receiving array to determine if the noise sources are localized.

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