DEPENDENCE OF AIRBORNE SURF NOISE ON WAVE HEIGHT

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1. INTRODUCTION

Airborne noise from breaking waves is an important component of the ambient noise in coastal areas. The surf noise may mask unwanted noise arising from sources such as offshore wind turbines or naval gunfire exercises. Work is being undertaken on behalf of the Department of National Defence (DND) to determine whether naval gunfire exercises may have an impact on bird colonies, nesting areas, or other sensitive sites on land in close proximity to naval operational areas. In order to determine whether the received sound pressure level from naval gunfire is above the ambient sound level at these sites, the ambient sound level in coastal areas as a function of sea state and weather conditions needs to be understood.

Underwater noise originating from breaking waves has been well-studied (e.g., [1]); however, there are fewer published papers on the corresponding airborne noise. Bolin and Åbom [2] measured airborne surf noise in third-octave bands as a function of significant wave height in ten locations along the Baltic Sea coast. They proposed several mechanisms for sound generation, including impact noise, single oscillating bubbles, collective bubble oscillation, and bursting bubbles; they also proposed a semi-empirical sound generation-propagation model. This paper describes a similar experiment and compares the results to those of Bolin and Åbom.

2. METHODS

A field trial was undertaken to study the relationship among ambient noise, surf conditions, and weather. Ambient noise levels were measured beginning on 1 June 2011 at Osborne Head, Nova Scotia (44° 36.70' N, 063° 25.20' W), on a grassy cliff 6 m above a rocky beach that experiences significant wave activity, 20 m from the high water mark. (The measurements are planned to extend into late August 2011; the data presented in this paper cover the period 1 to 21 June 2011.) The instrument used was a Brüel & Kjær (B&K) 2260 Observer fitted with an outdoor measurement kit and mounted at 73 cm height, set to record linear-weighted third-octave and broadband sound pressure levels with a 125-ms ("fast") time constant over 5-minute averaging periods. The calibrated measurements recorded by the B&K sound level meter included equivalent continuous sound level (L_{eq}), maximum and minimum levels (L_{max} and L_{min}), and percentiles such as the L_{95} (the sound pressure level exceeded 95% of the time). In addition to the calibrated measurements, five minutes' worth of uncompressed audio data were recorded every 30 minutes by sending the calibrated output from the B&K microphone through a National Instruments NI 9234 analog-to-digital converter using a 25600-Hz sampling rate. The resulting 24-bit *.wav* files were acquired using LabView software and saved to a laptop computer.

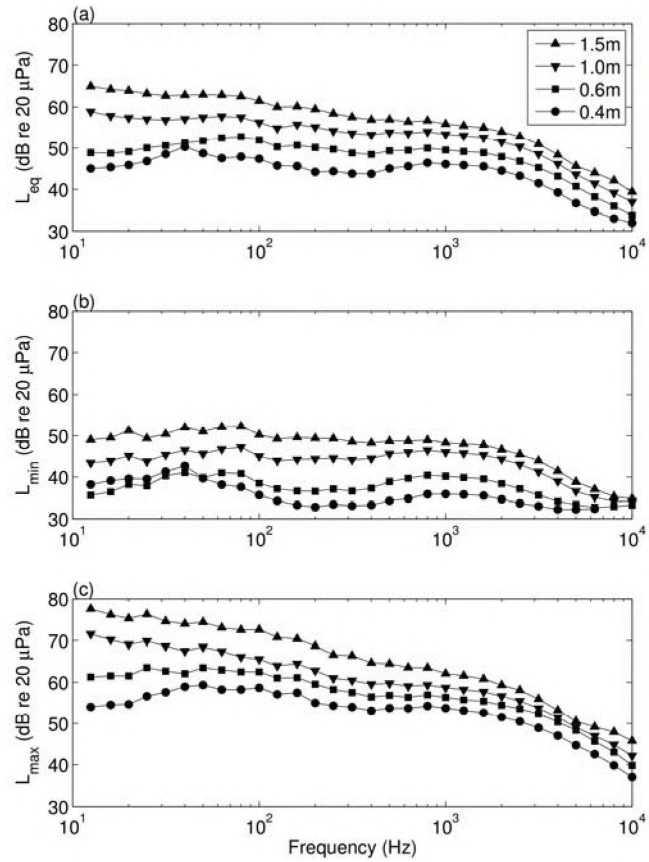

Figure 1 (a) L_{eq}, (b) L_{min}, (c) L_{max}, in third-octave bands for values of significant wave height indicated in the legend.

A self-contained Vaisala WXT 520 weather station was mounted on a pole at 10 m height to record environmental data at the site. A Teledyne RDI Acoustic Doppler Current Profiler (ADCP) was deployed 780 m SE of the measurement site, bottom-mounted in 11 m of water, in order to measure directional wave spectra. A qualitative record of breaking wave types was recorded with a camera mounted on top of a nearby building at the rate of 1 still photo every 5 minutes.

3. RESULTS

Figure 1(a) is a third-octave band spectrum of L_{eq} for significant wave heights between 0.4 m and 1.5 m. Not surprisingly, L_{eq} increases with increasing wave height at all frequencies. The spectrum above 100 Hz for L_{eq} has the same general shape for most wave heights: it remains reasonably flat (±3 dB) between 100 Hz and 1600 Hz, and it then drops off more steeply (between 5-6 dB/octave) for frequencies above 2000 Hz. Below 100 Hz, the spectral levels decrease for the 0.4-m and 0.6-m wave heights, and increase for the 1.0-m and 1.5-m wave heights.

Figure 1(b) is a plot of the third-octave band spectrum for L_{min} as a function of significant wave height, and Figure 1(c) is the corresponding plot for L_{max}. L_{min} is essentially flat below 1000 Hz for 1.5-m wave heights, and a broad peak near 1000 Hz for lower wave heights. For the 0.4-m and 0.6-m wave height, L_{min} also has a second peak at 400 Hz. L_{max} increases with decreasing frequency above 100 Hz for all wave heights, and shows a similar pattern to L_{eq} below 100 Hz (decreasing at low frequencies for 0.4-m and 0.6-m wave height, and increasing at low frequencies for 1.0-m and 1.5-m wave height).

4. DISCUSSION AND CONCLUSIONS

Interestingly, the third-octave spectra in Figure 1 are rather different than the results presented in Fig. 3 of Bolin and Åbom [2]: for significant wave heights less than 1.0 m, their spectra show a distinct broad peak near 1000 Hz, with a shifting of the peak to 250-400 Hz for significant wave heights greater than 1.0 m. However, direct comparisons are difficult because it is not clear from Bolin and Åbom's paper what exactly was plotted for the third-octave spectrum. It is assumed that they were measuring the peak sound pressure level in each third-octave band because the *y*-axis in Figure 3 of their paper is labelled L_p (dB). Aside from possibly measuring different quantities, the differences between the datasets likely arise because the experiment described here differed from Bolin and Åbom's experiment in two key ways. First, in this experiment, the ADCP is deployed within 1 km of the measurement site; in contrast, Bolin and Åbom used a combination of wave height data from wave buoys (30-200 km away) and a wave prediction model. Local bathymetry modifies the wave field and has a significant impact on the character of the breaking waves [3]. Second, the Osborne Head measurement site consisted of a grass-covered cliff where the microphone was placed that dropped sharply to a gravel and rock seabed and beach; in contrast, all the sites described by Bolin and Abom were gravel, rock, or sand. The noise of wind through the grass was clearly audible in the Osborne Head recordings, therefore, it is not surprising that the spectra differ, especially at lower frequencies, where grass noise can be significant [4].

In choosing the Osborne Head measurement site, the difficulties posed by the grassy cliff were not appreciated until the experiment was well underway. The 1-m tall grass had the effect of shielding the microphone from the substantial wind noise and turbulence present at the edge of the cliff, which varied significantly with height above the cliff. The choice of microphone location was guided by the desire to have measurements that are representative of the environment experienced by nesting birds, weighed against the likelihood of losing the equipment during a storm.

Considering the environment near the microphones, the spectra in Figure 1 are likely a superposition of sound originating from three sources: (a) breaking waves [1], (b) wind interacting with the grass [4], and (c) inherent turbulence in the flow [5]. The nature of breaking waves, which consist of louder "crashes" followed by "lulls" between breaking wave events, suggests that the noise spectrum observed for L_{min} may be a superposition of the noise from more distant waves and the wind through the grass, whereas the observed spectrum for L_{max} is likely dominated by nearby wave breaking events. Assuming 7-s period waves, the 5-minute averaging period for L_{eq} would include 43 breaking wave events averaged into one quantity. The fact that the spectral levels increase at low frequencies and higher wave heights (which are associated with higher wind speeds) for L_{eq} and L_{max} suggests that the low-frequency component is caused by the inherent turbulence in the airflow that is observed at higher wind speeds outdoors [5].

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