Recorded noise as a source for measurement of propagation loss.

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ABSTRACT

Repetitive bursts of recorded reef noise were broadcast from an underwater loudspeaker and used to measure propagation loss in shallow water. The method has advantages because sound levels in the bandwidth of interest can be measured directly and give a simple determination of attenuation due to bottom interaction. Surface scattering can be neglected because it does not contribute to energy loss when the signal of interest is recorded noise. A comparison of summer and winter results gives a direct measure of the extra propagation loss due to downward refraction.

INTRODUCTION

In shallow water acoustics various mechanisms contribute to the decay of sound level with distance from the source. This decay is generally called propagation loss or transmission loss and is well known to be a function of sea state, sound speed profile and bottom structure (Ainslie 2010, Brekhovskikh and Lysanov 1982, Harrison 2003, Marsh and Schulkin 1963, Urick 1983, Weston 1971). One of the components of propagation loss is attenuation due to repeated reflection from the ocean bottom. In the present work we show how this attenuation due to bottom interaction can be measured directly.

The experiments reported below were conducted in order to estimate the distance at which an isolated reef could be identified as a source of biological noise. Recorded reef noise was transmitted as part of a study to determine how marine larvae use sound to navigate and find suitable settlement habitat (Tolimieri et al. 2000, Tolimieri et al. 2004, Radford et al 2007, Stanley et al. 2010, Vermeij et al. 2010).

Previous work does not appear to have considered the deliberate transmission of recorded noise. The use of random noise as a 'signal' has the major benefit that the results are little affected by small to medium surface waves and propagation can be measured regardless of the condition of the wind and waves. A small amount of energy will be scattered at angles greater than the critical angle and will be lost to the bottom. Such energy loss will have more effect on a coherent signal than on the incoherent noise used as a signal here. The propagating noise signal is scattered by surface waves but scattered noise is still noise so there is little energy loss associated with surface scattering. Provided there are no surface bubbles, energy loss is due only to attenuation associated with reflection at the ocean bottom. In high wind conditions bubbles near the surface due to extensive whitecaps would give a loss mechanism. The effects of surface bubbles and bottom attenuation could be distinguished by making measurements in various sea states.

In the present work we use recorded noise as a source signal. By turning the signal systematically on and off the presence or absence of signal at the receiver is easily observed and the results can be analysed to determine propagation loss and ambient background noise at the same time.

PROPAGATION LOSS

Propagation in shallow water is usually considered in three regions (Ainslie 2010, Brekhovskikh and Lysanov 1982, Harrison 2003, Marsh and Schulkin 1963, Urick 1983, Weston 1971). There is spherical spreading near the source before the sound is trapped by repeated reflection at surface and bottom. In the next region propagation is governed by a 'three halves law' as energy at higher angles (or in higher modes) is preferentially absorbed. This region is also called the 'mode-stripping' region. Finally there is cylindrical spreading corresponding to single mode propagation at long ranges. Weston (1971) also adds a region of cylindrical spreading between the spherical and three halves regions. The transition between these regions depends on frequency and bottom parameters. In all cases there is also steady attenuation with distance due to scattering and absorption at the ocean bottom.

In the present work we find that propagation loss results do not conform to the three halves spreading law expected at intermediate ranges. Instead we find the data can be fitted by assuming cylindrical spreading plus bottom attenuation. This is in agreement with the simple physical assumptions that the sound is trapped by total internal reflection at grazing angles less than critical and there is loss of energy by absorption at each bottom reflection.

RESULTS

Experiments were conducted near the New Zealand coastline in October 2008 and February 2009. A source was suspended 2 m below a surface float in 50 m of water. A receiver at 20 m depth was deployed at various distances from the source towards deeper water out to a range of 8 km. The water depth increased steadily to 55 m. The transmitted signal was a series of noise bursts 10 seconds long separated by 5 seconds of silence. The noise was recorded reef noise and had a broad peak in the range 800-1500 Hz.

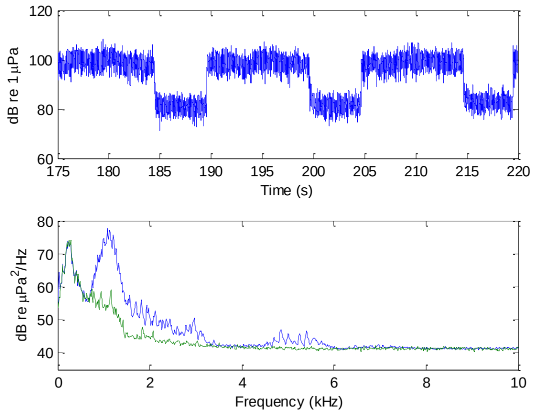

Figure 1. Sound pressure level in 800-1500 Hz band and unfiltered spectra. Upper spectrum is during recorded noise burst. Lower spectrum is background noise. Data taken in southern summer (February 2009) at range 4 km.

An example of the processed signal is shown in Fig. 1. The data was taken in February 2009 at a range of 4 km. The top panel shows the intensity of the received signal on a dB scale re 1µPa and has been band-pass filtered to the range 800-1500 Hz. The intensity levels when the signal is present or absent are easily determined from the results. The lower panel shows the unfiltered spectrum of the received signal. The upper trace is the spectrum during bursts of transmitted noise and was obtained by analysing a combination of the three 10 second noise bursts of the upper figure. The lower trace shows the spectrum of the ambient background noise when the source was not transmitting and was obtained by analysing a combination of the three quiet sections of the upper figure.

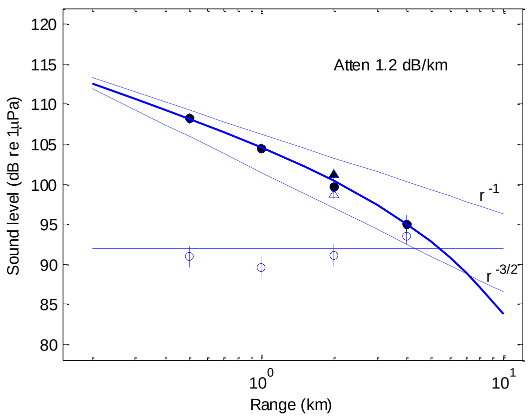

Figure 2. Sound pressure level vs range in the 800-1500 Hz band in late winter. Closed symbols are data for noise bursts. Open symbols are data for background noise. Circles are on outward run. Triangles are on return run. Solid curve is cylindrical spreading plus attenuation. Upper thin line is cylindrical spreading. Lower thin line is "three halves" spreading. Horizontal line is ambient noise level.

Results for sound level in the 800-1500 Hz band as a function of range are shown in Figs. 2 and 3. Figure 2 shows results taken in October 2008. There was an off shore wind of about 15 knots giving a significant wave height of about 0.5-0.8 m at the measurement locations. The closed circles and triangle show the sound level when the signal was present. For each point a total of 30 s of data was analysed in 1 s sections giving the mean and standard deviation shown. The open circles and triangle show the ambient noise level when the signal was not present. For each point 15 s of data were analysed in 1 s sections. The circle data points were obtained moving away from the source and the triangle data points were obtained on the return trip. During the outward journey the ambient noise increased slightly from 91 dB to 93 dB re 1 µPa.

The data points at 4 km were obtained on both the outward and return journeys and were taken about 4 hours apart. The signal level was unchanged but the ambient noise level had increased to about 98 dB re 1 µPa because the wind had strengthened.

The signal level decreases as a function of range as expected. The upper and lower thin lines show cylindrical and 'three-halves' spreading respectively and, as expected, both are straight lines on a plot of sound level vs log(range). The data of Fig. 2 could be fitted with the three halves law because it has a similar slope but we prefer to analyse the data of both Figs. 2 and 3 with the same theoretical curve. The solid curve is a good fit and is obtained by assuming cylindrical spreading and bottom attenuation. As noted above, even though surface waves were present the scattering of energy at the surface does not represent significant energy loss from the water column. There is also no energy loss due to scattering at the ocean bottom. Therefore the only loss mechanism is attenuation due to partial reflection at the ocean bottom and this is estimated by fitting the data of Fig. 2. The value obtained is 1.2 dB/km for the frequency band 800-1500 Hz.

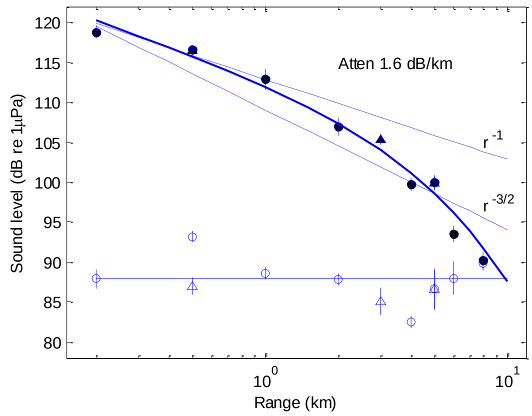

Figure 3. Sound pressure level vs range in the 800-1500 Hz band in summer. Closed symbols are data for noise bursts. Open symbols are data for background noise. Circles are on outward run. Triangles are on return run. Solid curve is cylindrical spreading plus attenuation. Upper thin line is cylindrical spreading. Lower thin line is "three halves" spreading. Horizontal line is ambient noise level.

Figure 3 shows results taken in February 2009 at locations which include all those of Fig. 2. Conditions were calm with 0.5 m swells. The open circles and triangles show the ambient noise results for outward and return journeys respectively. The mean level is about 88 dB re 1 µPa. The value of 93 dB at 500 m range is due to a nearby fishing vessel. The closed circles and triangles show the level during transmission of the recorded reef noise. The upper and lower thin curves show cylindrical and three halves spreading respectively and do not fit the data. The solid curve is for cylindrical spreading with bottom attenuation of 1.6 dB/km and is a good fit to the data.

The data for Figs. 2 and 3 were obtained in the same experimental location. The different values for bottom attenuation have occurred because the measurements were done at different times of the year. The data in Fig. 2 was obtained in late winter when the water would have been approximately isovelocity. The data in Fig. 3 was obtained in mid-summer when there would have been warm surface layers and a strong downward refracting sound speed profile giving more bottom interaction and enhanced attenuation. We conclude that the downward refracting summer conditions have led to an extra 0.4 dB/km of bottom attenuation.

DISCUSSION

The experiments described above give a simple method of measuring attenuation due to bottom loss in shallow water. The advantage of using recorded noise as a signal is that scattering due to surface waves does not lead to significant energy loss and does not affect the results.

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