Ambient noise measurements in the surf zone

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Abstract

Surf noise makes a significant contribution to the ambient noise field in the near-shore region. Knowledge of surf noise is therefore important in the design of active and passive acoustic systems for operation in littoral waters. Time series measurements of surf noise have been made using an array of hydrophones deployed just offshore of the surf zone. The relative contributions from the main sources of noise are assessed.

1. Introduction

Knowledge of coastal ambient noise levels is important in the design of active and passive acoustic systems for operation in littoral waters. The background noise level limits the performance of sonar systems and also forms the baseline for the assessment of their environmental impact. It is also important for assessing the impact of near-shore commercial and leisure activities on the natural environment.

The study of ambient noise in the open ocean and in coastal waters is a well-established field, but few researchers have addressed the nature of the sources and the properties of ambient noise due to surf. A large proportion of the published work describes measurements made between 500 m to a few kilometres offshore [1-3]. Reference 1 shows how noise due to surf on a sandy beach can make a significant contribution to the ambient noise field in the near-shore region.

More recently, an increased effort has been made in the understanding of the noise generation processes in the surf [4-7]. Deane [5-7] describes a series of model-experiment comparisons of the source characteristics of surf on a sandy beach at La Jolla Shores, California. Ringing bubbles were found to dominate the breaking wave noise spectrum [5] and acoustically active regions (hot-spots) were associated with compact sources at the ends of the breaking wave crest [6]. Correlation analysis of long-period observations established that the surf noise level depends on the incident wave height [7]. Models have been developed for the directional characteristics of noise in the surf zone [8-10].

The work described in the preceding paragraphs is based on measurements offshore of sandy beaches where the dominant noise source is the ringing of bubbles entrained during the breaking process. Noise measurement [11] around two pebbly ocean beaches and a rocky inland seacoast showed that the primary acoustic source can be the impact noise of pebbles agitated by the waves.

This paper presents preliminary results of an experiment that has been conducted to quantify the relative contributions of sediment generated noise and bubble noise to the ambient noise spectrum in the vicinity of a pebbly beach.

2. Acoustic Source Mechanisms

The ambient noise spectrum measured offshore of the surf zone depends upon the incident wave characteristics, the sound generation and loss mechanisms in the surf zone, and also on the nature of the propagation between generation and measurement. There are a number of different source mechanisms, the relative importance of which will depend on the nature of the environment. This dependence of the ambient noise spectrum on the environment leads, in principle, to the possibility of inverting remote acoustic measurements of the in-water ambient surf noise spectrum to infer the properties of the environment, such as surf and beach characteristics.

Breaking waves in the surf zone generate sound through a number of different mechanisms. The sound sources are located in the breaking region and radiate from a few tens of Hz to 500 kHz or more. Possible mechanisms include the sound associated with the entrainment of air, including free bubble oscillations and collective bubble oscillations, splashes, sediment generated noise, *surfseisms* and turbulence. Much of the recent literature on the surf noise generation mechanisms has been reviewed by Deane [5]. Figure 1 indicates the spectral extent of the various contributions to the surf noise spectrum. At this stage it is not possible to represent these contributions as Knudsen spectra, as we do not know the source levels associated with the different mechanisms.

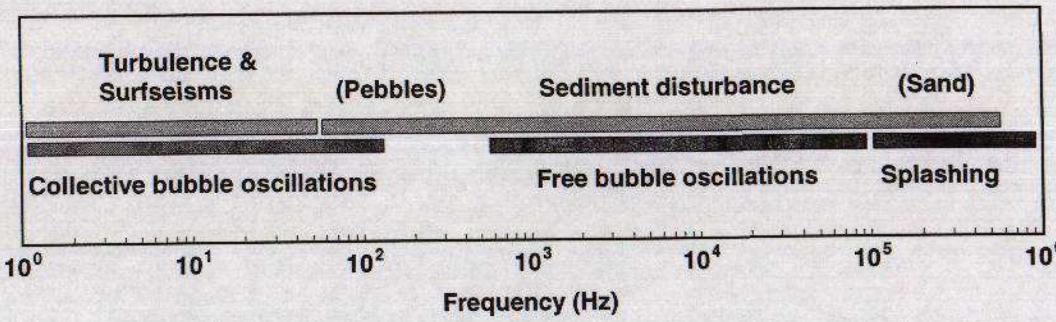

Figure 1. Contributions to the surf-zone ambient noise spectrum

In considering the relative magnitudes of the noise produced in the surf zone, various mechanisms involving bubbles appear to be the primary source of sound in the breaking region. Collective oscillations of bubble clouds and plumes are a major sound source below 100 Hz, with single bubble oscillations dominating the radiated sound spectrum from 500 Hz to 50 kHz. On sandy beaches it is unlikely that sediment disturbance will contribute much below about 100 kHz, but gravel and pebbles, where present, could contribute significantly at lower frequencies.

3. Surf Zone Ambient Noise Experiment

3.1 Introduction and Objectives

The previous section identifies distinct noise components in surf noise, which can be linked to specific noise generating processes in the surf zone. An experiment has been conducted with the aim of quantifying the various contributions, which will assist in the development of predictive models. In the experiment described in this paper, the noise contribution due to sediment disturbance was significant.

The experimental approach was to deploy an array of four hydrophones (Figure 2) just offshore of an active surf zone. The hydrophone-pairs were arranged on three axes and spaced for cross-correlation signal processing at frequencies above 1 kHz. The array was designed for robustness and easy deployment in the surf zone. In the experiment, the separation of the hydrophones in each pair was 50 cm, half the acoustic wavelength at 1.5 kHz.

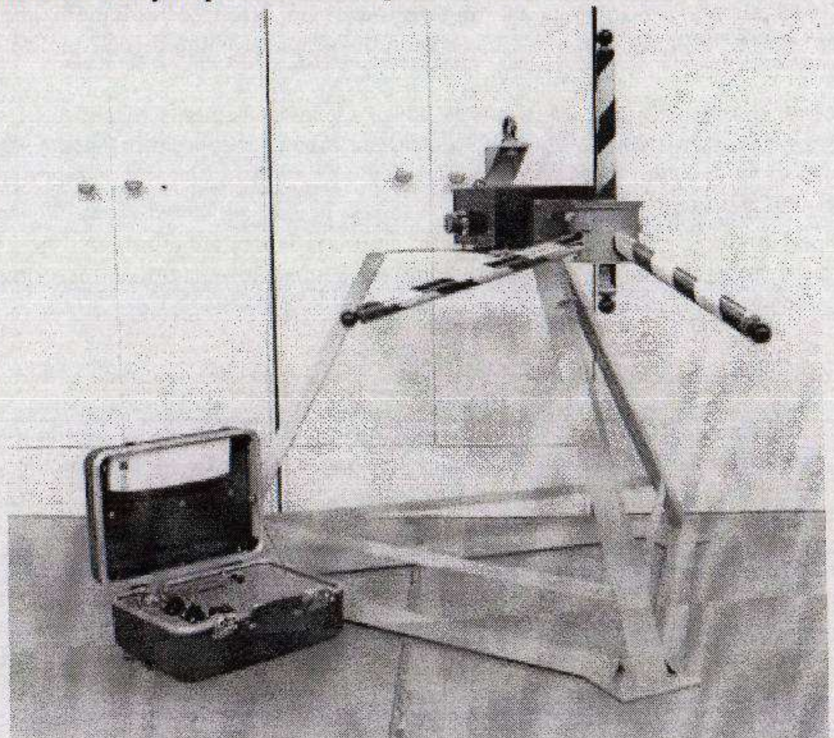

Figure 2. Noise measurement array, with experimental instrumentation and supporting tripod

3.2 Experimental site

The experiment was conducted at Arish Mell beach in Worbarrow Bay, Dorset (Figure 3). The beach lies in the middle of Worbarrow Bay and is flanked by steep cliffs. A beach survey was conducted at the time of the experiment and samples of the beach material were measured. The beach is a mixture of gravel (diameter 0.2 cm to 0.5 cm), pebbles (1 cm to 5 cm) and larger stones (10 cm). The beach was steep (mean slope of 14%) and noticeable berms (steep banks 0.75 to 1.0 m high) were present. A previous survey indicated that the beach profiles were susceptible to short-period changes following South-westerly winds. This was confirmed by observations of the beach profile made over the one-week experimental period.

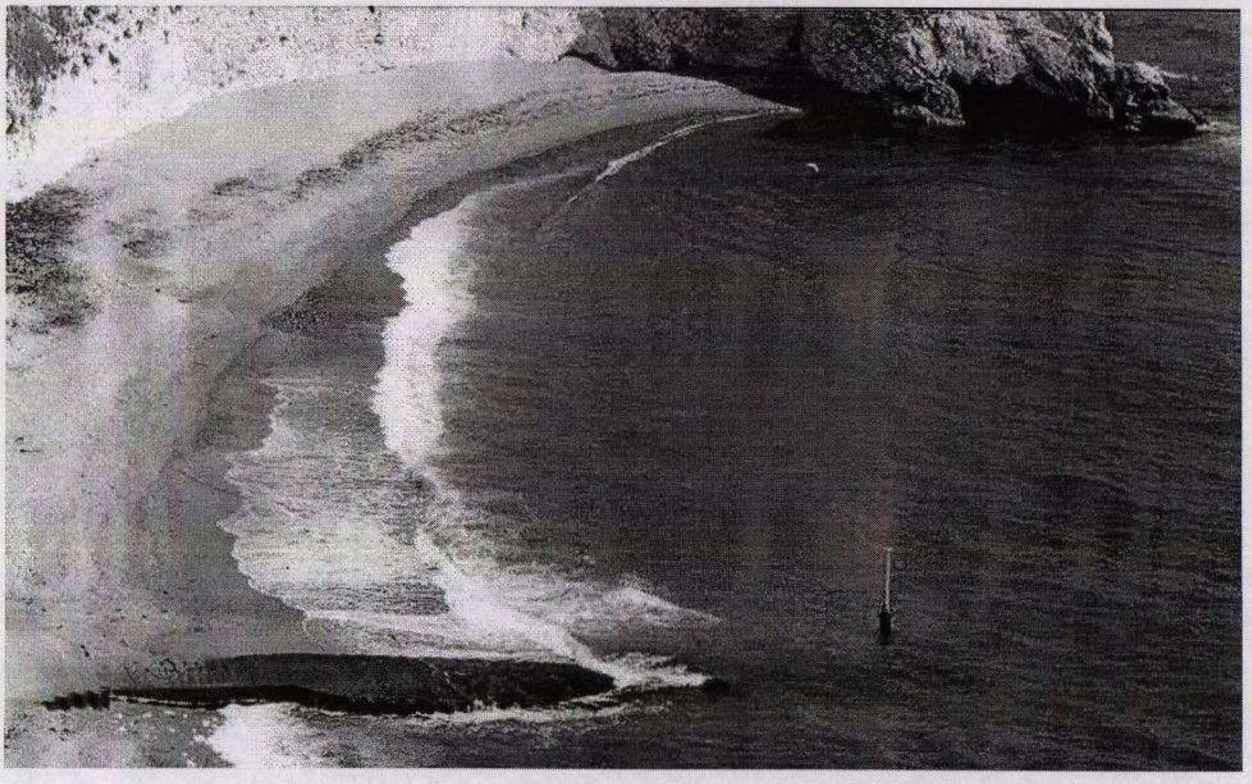

Figure 3. Experimental site - Arish Mell Beach, Worbarrow Bay, Dorset

3.3 Conduct of the Experiment

The acoustic array was deployed on the tripod frame in 5 m of water, 40 m from the shoreline at low water. An instrumentation package provided information on the direction and orientation of the array, together with recordings of *in situ* water depth and wave time series. Video recordings were made of the surf zone and a weather station was deployed nearby. Acoustic time series and video recordings were made at hourly intervals on two consecutive dates (23 and 24 July 2000) and covering two 12-hour tidal cycles. Throughout the observation periods, the surf zone was very narrow with one line of surf and the waves were observed to plunge directly on to the beach. This was expected from the steep slope of the beach and the characteristics of the incident waves.

3.4 Results

Figure 4 is a frequency-time spectrogram of 30 s duration taken from the recorded time series. The variation in the spectral amplitude of the surf noise is displayed as a function of time. Signal frequencies from below 100 Hz and up to 20 kHz were recorded.

The main feature of this data is the occurrence of short bursts of high noise level, at a repetition rate corresponding to that of the breaking surf. The incident wave period was around 6 s, but the number of peaks in the spectrogram is greater than would be expected from wave breaking alone. There are between 8 and 10 noise bursts – corresponding to a wave period of 3-4 s. It was noticed that the latter stages of some wave breaking events included episodes of impulsive noise. Audio monitoring (listening to the noise) showed that the impulses were identifiable as a characteristic of the collision of pebbles and stones in the backwash. This conclusion is supported by visual observations of the water in the region of the breaking waves, which revealed that, although the breaking action led to the suspension of particles from the seabed, the greatest disturbance and mobility of sediment occurred during the backwash. The additional peaks in the spectrogram have therefore been attributed to sediment generated noise during the backwash.

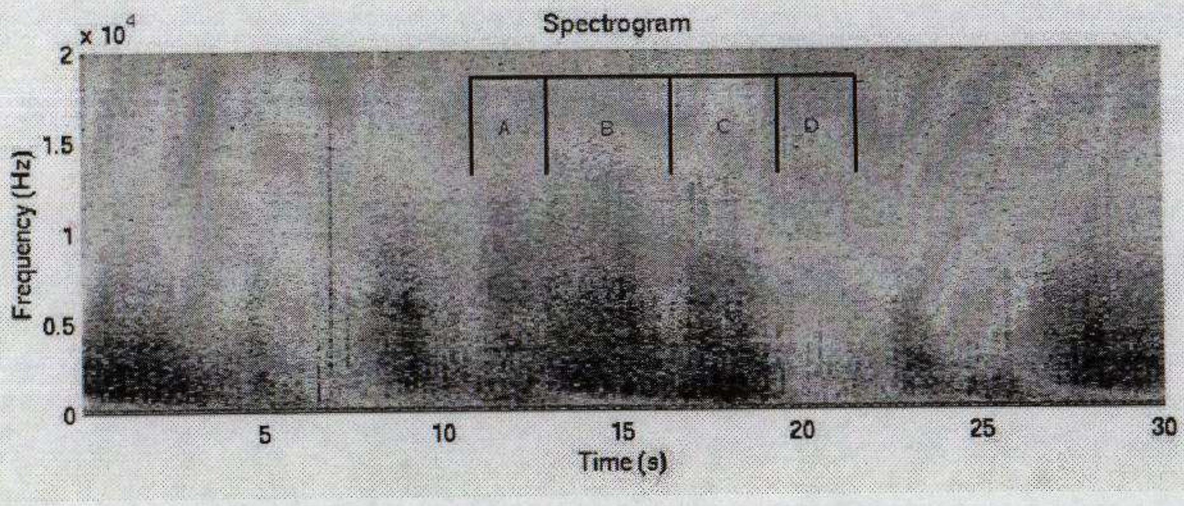

Figure 4. Frequency-time spectrogram

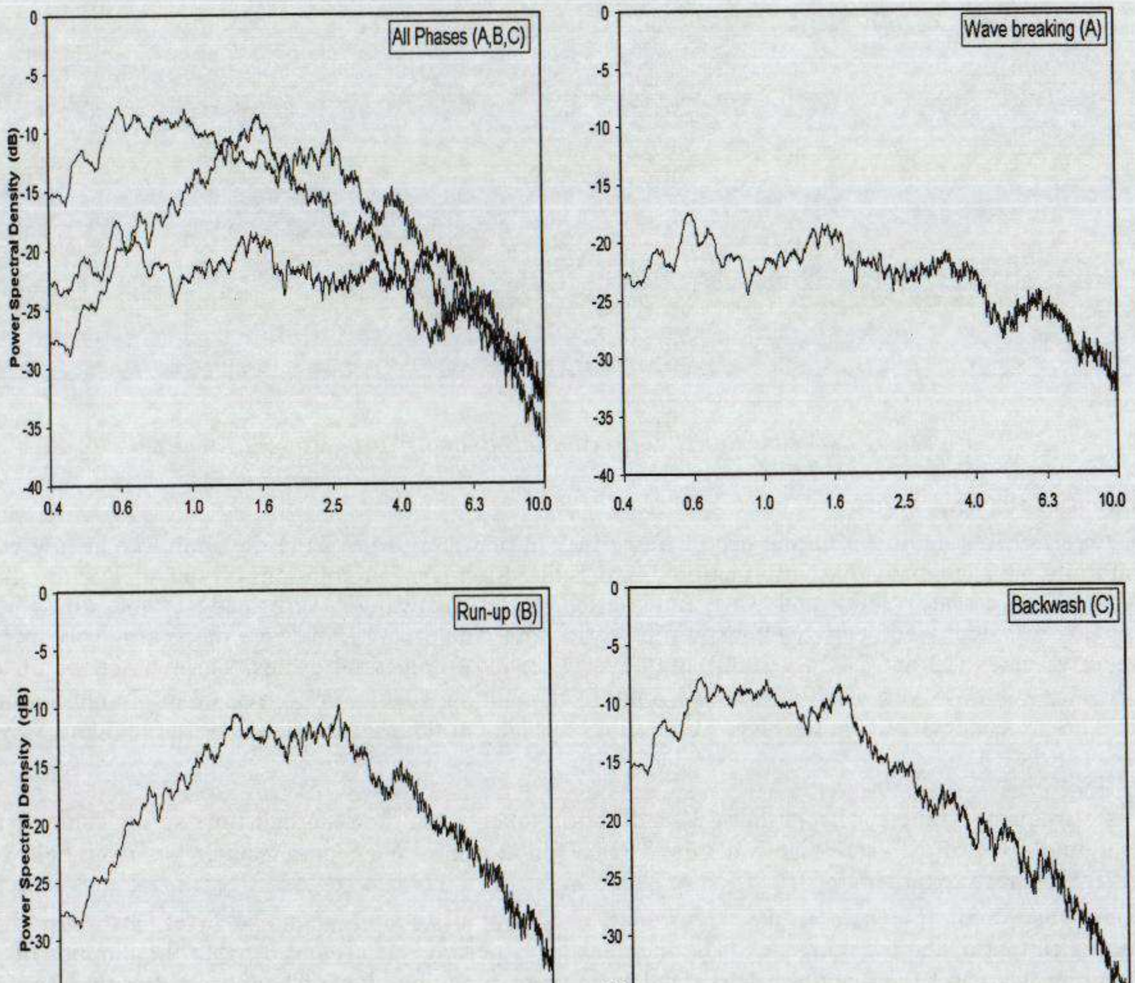

Figure 5. Power spectral density for phases A, B and C of breaking event in Figure 4 (arbitrary dB reference)

Of particular interest is the sequence of noise bursts between 11 s and 23 s. A comparison of the video record with this time series data indicates that this sequence corresponds to a single wave-breaking event. The apparently long duration is due to the wave being incident on the beach at a slightly oblique angle; this extends the noise burst as the wave breaking point moves from East to West along the beach. The video record also indicates that the first two noise bursts were due to the initial plunging of the wave (A), followed by the run-up of the surf up the beach (B). Although bubble resonance was expected to be the dominant noise source during the wave breaking and run-up, audio monitoring indicated the presence of some sediment generated noise during the run-up. The third, separate burst was identified as backwash, with the audible impulsive sounds of sediment generated noise visible as vertical streaks in Figure 4 (C). The sequence is followed by a quiescent period (D).

The sequence of noise bursts between 11 s and 23 s of this record has been subjected to further analysis to establish the relative contribution of sediment generated noise. The variation in the shape of the noise spectrum is not obvious from Figure 4, but can be seen clearly in a series of individual spectra showing the phases of the wave breaking event (Figure 5). A time series has been generated (Figure 6) covering the period 11 s to 23 s of this record, and showing the variation in the total power (dB) summed within each of four octave bands. The amplitude scale is normalised to an arbitrary reference and time scale is the same as in Figure 4.

The observed overall power variation with time in Figure 6 can be linked to the noise bursts in Figure 4. The peak power is greatest in the 1-2 kHz and 2-4 kHz bands and is at least 20 dB above the quiescent level. The peak for the 4-8 kHz band is about 17 dB and for the 8-16 kHz band it is 12 dB. This demonstrates that surf noise has a large dynamic range, particularly at the low frequencies that propagate well and could thus impact on sonar operations in the littoral.

Of interest to the noise source analysis is how the *relative* levels of the octave bands vary during the record (Figures 5 and 6). In Figure 6 this variation is most apparent for the 1-2 kHz and 2-4 kHz octave bands. At wave breaking (A ~12 s) the power levels in the two lower octaves are similar. During run-up (B ~14-15 s) the 2-4 kHz band is highest, but the 1-2 kHz band increases gradually and becomes the highest during the backwash (C ~17-19 s). This trend can also be seen in Figure 5. As the wave breaks (A), the power is low overall, but is relatively higher at frequencies above 5 kHz, consistent with resonant bubble noise. There is an overall increase in power during wave run-up (B). In the backwash (C) the lower frequency noise is enhanced, but the higher frequency noise is decreases. These trends are consistent with a change in the dominant noise generation mechanism from bubble resonance to sediment disturbance.

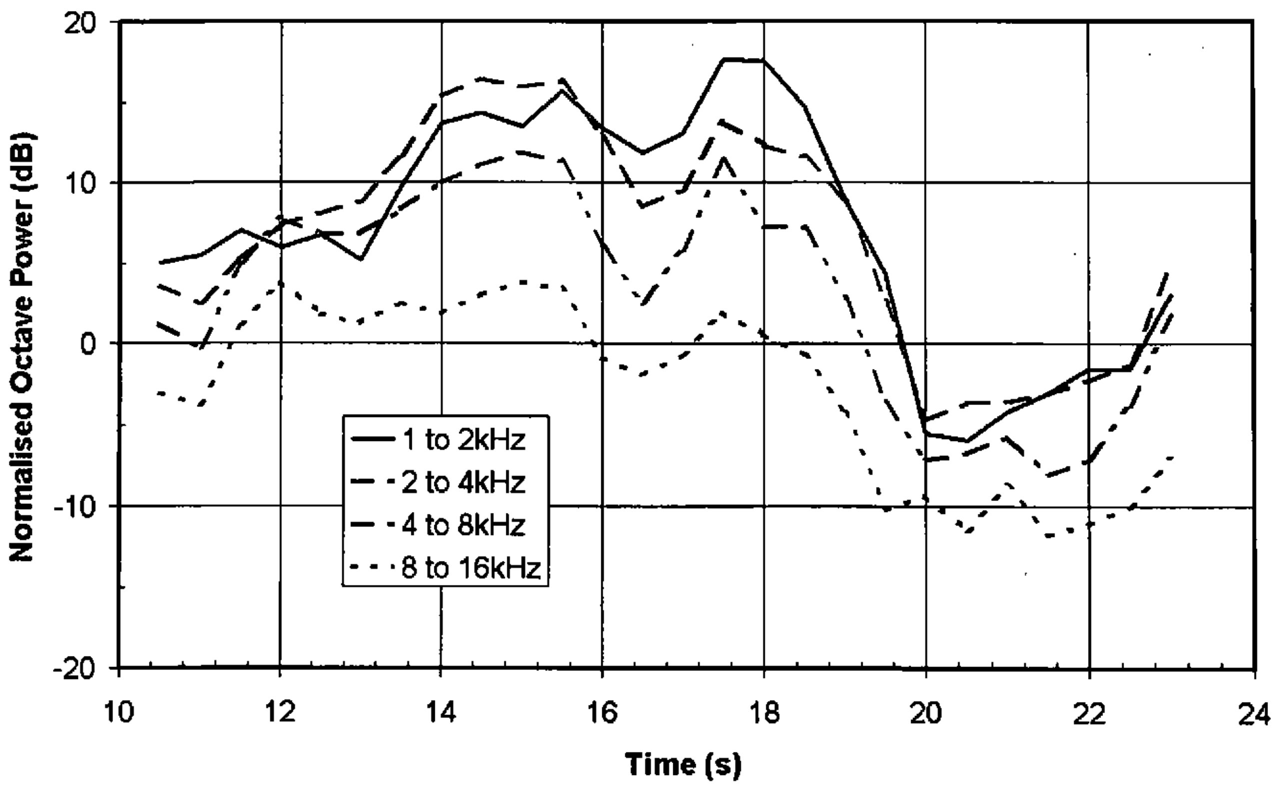

Figure 6. Time series of breaking event in Figure 4: power summed in four octaves (arbitrary dB reference)

4. Discussion

Audio monitoring has indicated that sediment generated noise dominates the surf noise during backwash and this appears to be associated with the observed large increase in low-frequency noise. The disturbance of sediment is known to lead to sound generation through inter-particle collisions. This is conventionally known as saltation noise although saltation describes the sudden, leaping movement of sediment particles caught in a current and not the particle collisions *per se*. The sound from a rigid-body collision has a spectral shape that has the approximate form of a simple band-pass filter, with a broad peak. The peak frequency and amplitude are determined by the particle sizes [12]: as the sediment grain sizes increase, the cutoff frequency decreases and the power spectrum level increases [13, 14]. Thus pebbles make a more significant contribution, and at a lower frequency, than gravel or sand. An additional factor which may contribute to the change in the shape of the spectrum is attenuation of the sound at the higher frequencies by the passive bubbles that were laid down during the wave breaking and run-up.

An estimate has been made of the particle size corresponding to the measured spectrum for sediment generated noise on the experimental beach (Figure 5, Backwash). This estimate is based the relationship between the impact duration time and frequency characteristic for rigid-body collision [14]. The spectrum has an irregular peak between 0.6 kHz and 1.7 kHz, corresponding to a particle diameter of ~9 cm. Although this estimate is taken from a single event, it is consistent with the size range of the pebbles and stones found on the beach (1 cm to 10 cm). Furthermore, it would be expected that the larger particles would be expected to dominate the sediment generated noise spectrum [14].

Further data analysis and modelling is required to establish the relative contributions of bubble noise and sediment generated noise. However, a preliminary conclusion is that it is possible to separate bubble and sediment noise, leading to the possibility of inverting remote measurements of surf noise to obtain information on the surf and beach properties.

The results presented here indicate that it may be feasible to provide estimates of the surf period and sediment particle size. Further analysis of the recorded data is required to determine whether quantitative inversion may be achieved for surf and beach properties (including breaker height and type, number of lines of surf, beach slope). Beach profiles are not constant and are subject to frequent, large changes due to wave action and the changing tidal height. However, a rough estimate of beach slope may be obtained from the average grain size of the beach material and the ambient wave steepness [15].

Acoustic propagation from the breaker zone to the measurement array will need to be taken into account as part of the inversion process. The main features that affect the propagation in the surf zone are the high concentration of bubbles and the beach/seabed slope. The simplest geometrical representation of a beach is a wedge, an environment that has received considerable attention for the calculation of acoustic propagation [16]. Such an approach is recommended as the starting point for modelling the beach environment.

The presence of resonant bubbles in the surf zone will influence propagation towards deeper water, as both individual bubbles and bubble plumes will strongly absorb and scatter the sound. In patches of high bubble concentration, the sound speed can be reduced to 500 ms^{-1} and acoustic absorption can be as high as 50 dBm^{-1} [10]. Similarly the presence of sediment particles, suspended in the water column by wave and current action, have been shown to absorb and scatter sound, particularly at high frequencies [17].

5. Conclusions

Surf noise makes a significant contribution to the ambient noise field in the near-shore region and it is therefore important to quantify its effect in the design of active and passive acoustic systems for operation in littoral waters. It is also important for assessing the impact of near-shore commercial and leisure activities on the natural environment.

Recordings of surf noise have been made using an array of hydrophones deployed just offshore of the surf zone on a pebbly beach. Analysis of a wave-breaking event is broken down into a sequence of phases, corresponding to the initial wave breaking, then the run-up and backwash of the water up and down the beach. Sediment generated noise was found to dominate the surf noise in the latter phase, and this appears to be associated with a large increase in low-frequency noise compared with the initial wave breaking. It is concluded that the changes in the frequency content of the surf noise are thus probably due to changes in the dominant noise source from bubble noise to sediment generated noise noise.

Further data analysis and modelling is required to establish the relative contributions of bubble noise and sediment noise. However, a preliminary conclusion is that it is possible to separate bubble and sediment noise, leading to the possibility of inverting for surf and beach properties.

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