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Reflection loss estimation using shallow water ambient noise in the Arabian Sea off the west coast of India

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ABSTRACT

This study focuses on the application of a recently developed array processing technique, for estimating the seabed reflection loss, using ambient noise in extremely shallow water (Siderius et al, 2013). According to synthetic array processing technique, the angular resolution of directionality and reflection loss derived from ambient noise can be improved. In this method, Toeplitz property of noise coherence function is used to improve the angular resolution in beamforming. The simulated result of the developed technique provides higher angular resolution for vertical directionality and reflection loss. Ambient noise data recorded in wind prevailing conditions, using a 12 element vertical array from the shallow waters off the west coast of India was used for the analysis. The results from the experimental data conclude that, the reflection loss derived from a 12 element physical array can achieve angular resolution, comparable to a synthetically expanded 6 element physical array.

1. Introduction

In underwater acoustics, background noise becomes a major concern when it interferes with the signal of interest. Wind, rain, marine life and ship traffic are the major sources of ambient noise in the Ocean. Among them, wind generated breaking waves at the ocean surface are a predominant and persistent source of ambient noise. Generally, background noise is considered as undesirable in ocean acoustic signal processing, but it contains information regarding the ocean environment through which the sound propagates. The received ambient noise level at a hydrophone depends on the source properties and sound propagating conditions of the ocean environment. Earlier studies reported that seabed geoacoustic parameters can be estimated from acoustic remote sensing, especially using passive techniques (Buckingham and Jones, 1987; Carbone et al., 1998; Harrison and Simons, 2002). The spatial properties of ambient noise, such as coherence and directionality, are generally used for extracting seabed parameters from ambient noise. As explained in earlier reports (Harrison and Simons, 2002; Harrison, 2004) wind induced ambient noise measured using a vertical array, contains information regarding seabed reflection loss and sub bottom layering. Seabed reflection loss plays a critical role in the accurate prediction of transmission loss, especially in shallow waters. Transmission loss is a major factor in both active and passive sonar performance modelling.

According to Harrison and Simons (2002), the seabed power reflection coefficient can be computed from the ratio of upward to downward energy flux, by beamforming the ambient noise measured using a vertical hydrophone array. The length of the array and number of hydrophones are primary factors to retrieve high resolution reflection loss, over a frequency band and angular range. In the case of short arrays, angular resolution has to be compromised, even though they are cost effective and easily deployable. Reflection loss derived from short arrays may create error in transmission loss estimates due to poor resolution. Thus, improving the angular resolution of the received ambient noise on a vertical array has a significant impact on sonar performance modelling. Siderius et al (2013) developed Synthetic Array Processing technique (SAP), to improve the angular resolution of reflection loss derived from ambient noise. In this technique, the Toeplitz property of ambient noise is used to improve the angular resolution in beamforming (Buckingham, 1980). Toeplitz property suggests that, noise spatial coherence between two hydrophones depends only on their separation, and not on their absolute position in the water column. By applying this property, the angular resolution of directionality and reflection loss, estimated from a vertical array can be improved to a level comparable to that of an array, with twice the number of sensors. In a real ocean environment this technique can be implemented, if the background noise is dominated by, surface distributed sources such as the wind

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(Muzi and Siderius, 2013). A latter study discussed the practical application of the technique for seabed geoacoustic inversion based on coherence extrapolation (Quijano et al, 2014). The extension of SAP technique for variable sound speed profile and attenuation, as well as validation with experimental data, has been reported very recently (Muzi et al, 2015).

The purpose of this study is to report and discuss the suitability of synthetic array processing technique, to the ambient noise data from a vertical linear array in the shallow waters of the Arabian Sea. Harrison's ray based ambient noise model is used to simulate the noise Cross Spectral Density matrix (CSDM), for explaining the processing technique (Harrison, 1996). Later, the technique is applied to derive vertical directionality and reflection loss from the measured ambient noise data, using a short array consisting of twelve hydrophones. Applying the SAP technique to the measured data, shows improvement in the angular resolution of vertical directionality and reflection loss, when there is no interference from other sources such as shipping.

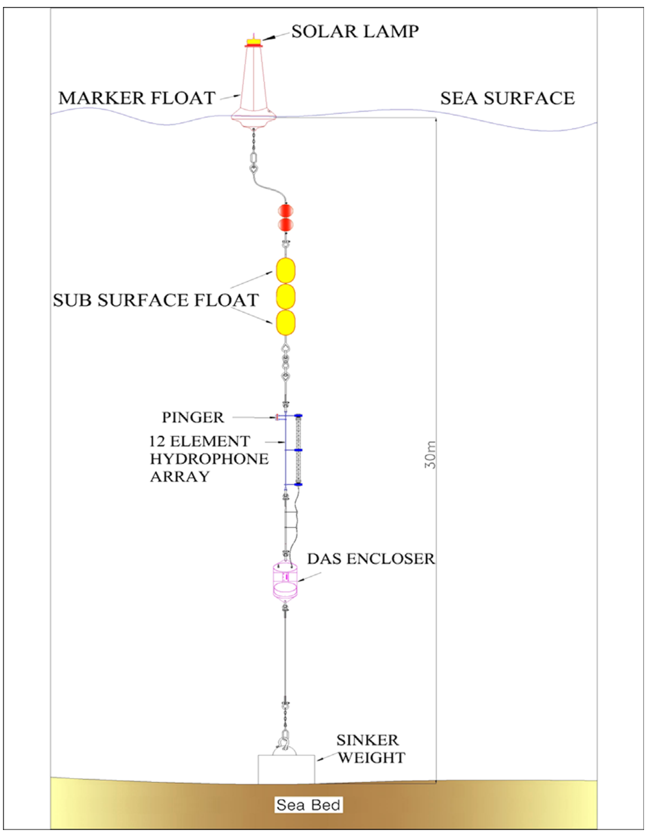

Fig. 1. Subsurface system for ambient noise measurement.

2. Measurements and processing methodology

2.1. Data collection

An automated subsurface noise recording system was developed and deployed at 30 m water depth, for the time series measurements, off the Cochin coast in the Arabian Sea. The system was deployed from April 2011 to June 2011 and the datasets measured during peak summer, were used for analysis. The Measurement system consists of a data acquisition module and a vertical linear array of 12 hydrophones, with uniform sensor separation of 0.15 m and the schematic of the system is shown in Fig 1. The hydrophone array is positioned just above the mid-water column. The omnidirectional hydrophones in the array are capable of measuring noise in the frequency range 0.1–10 kHz with a receiving sensitivity of −170 dB re 1 V/μPa. Noise data was recorded for 30 s with eight samples in a day, at intervals of 3 h at 50 kHz sampling frequency. In addition to ambient noise, other environmental parameters such as wind speed, sediment samples and sound speed profile from the site were also collected.

2.2. Synthetic array processing

Based on Harrison and Simon's (2002) derivation, the seabed reflection loss can be estimated from the ambient noise data from an array, by the ratio of upward looking (reflected) beams to the downward looking (incident) beams.

$$R(\theta) = B(-\theta)/B(\theta) \quad (1)$$

where $R(\theta)$ is the plane wave reflection coefficient of the seabed, for a wave front hitting the bottom at a grazing angle θ. Using the plane wave reflection coefficient derived from the beamformed output, seabed reflection loss can be estimated as

$$RL(\theta) = -10\,Log(R(\theta)) \quad (2)$$

In order to beamform using the conventional technique, the beampower output in terms of frequency and steering angle is defined as (Krim and Viberg, 1996)

$$B(\varphi, \omega) = w^{\dagger} p \left(w^{\dagger} p\right)^{\dagger} = w^{\dagger} p p^{\dagger} w = w^{\dagger} C_{\omega} w \quad (3)$$

where † denotes the conjugate transpose operation, and w is the weight vector for the steering angle φ. $p(\omega) = [p_1, p_2, \ldots p_m]$ is the

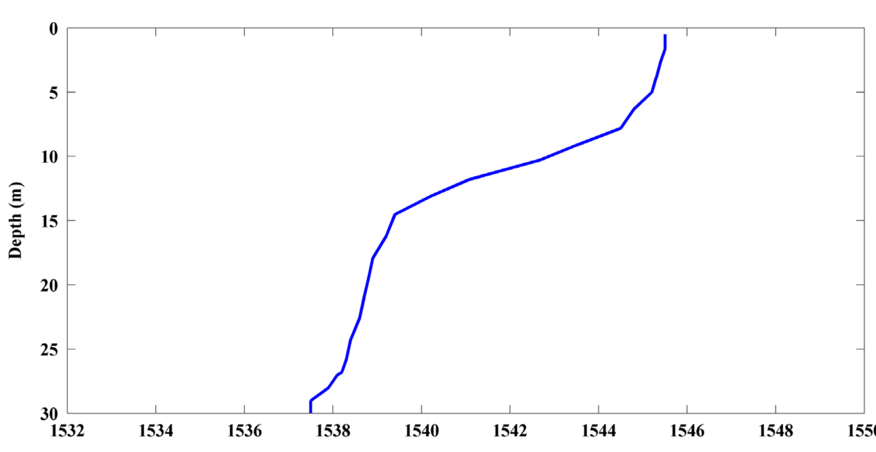

Fig. 2. Measured sound speed profile of the site.