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Shallow ambient noise variability due to distant shipping noise and tide

Arnab Das *

Underwater Ranges, Indian Navy, Vasco-da-gama, Goa 403 802, India

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ABSTRACT

Study and characterization of distant shipping component of ambient noise in shallow water aid in design of passive surveillance algorithms and effective signature analysis of marine vessels. This letter presents the work carried out on real ambient noise recording in very shallow water condition close to a commercial port with heavy shipping activity to study and characterize the distant shipping noise component for variations due to tide. Ambient noise recording was carried out by a bottom mounted sensor at 30 m depth at regular interval for a period of over one month and the spectrum in the band 10–1.6 kHz was characterized for its diurnal spectral variation. The study concluded that the distant shipping noise component due to heavy small vessel activity in the nearby port resulted in up to 35 dB variation in the shallow water ambient noise in coastal areas that may have serious implication on passive surveillance algorithms performance in the vicinity if adequately not addressed. This is the first such effort in ambient noise measurement and characterization in the extremely shallow water channel condition prevalent in the tropical waters off the west coast of India.

1. Introduction

The security scenario and the consequent concern for developing effective passive surveillance systems draws our attention towards generating awareness about the ambient noise behavior that cause severe limitation in the performance of such systems [1,2]. Ambient noise literature covers a large range of aspects concerning ambient noise [3–10]. In any passive surveillance system the signal of interest occupies the lower frequency band up to 1.5 kHz and the distant shipping noise component of the ambient noise dominantly overlaps the same band [2]. To make matters worse for a passive surveillance algorithm designer, the distant shipping noise levels can be as much as 40 dB higher than the local wind-noise levels [11]. The progressive shift of the naval as well as commercial activities to the littoral waters has resulted in the sonar performance getting limited particularly due to higher ambient noise levels and also due to ambient noise characteristics being unique to the particular location. Any effort to improve the Signal-to-Noise-Ratio (SNR) necessitates that the ambient noise behavior and particularly the distant shipping noise component is characterized comprehensively.

Urick [3] in his book on ambient noise does bring out the shallow water ambient noise variability. Propagation characteristics do affect the ambient background in shallow waters though in a different way than it does distant shipping noise in deep water. Measurements carried out in the Bristol Channel [12], separating England and Wales in 39 m of water, has reported strong propagation dependent ambient noise variation due to tidal cycle. Similar work [13], in 3-foot (<1 m) range of tide in 60 ft. (19 m) of water reported up to 15 dB change of the levels from a source 1 mile away. Ambient noise variability due to wind has been widely reported [2–5,14] by numerous researchers. In the Indian subcontinent real data collection and analysis is extremely limited. Some efforts have been made to study and characterize the shallow water ambient noise behavior in the eastern coast with reference to wind and biological noise [15,16].

In this work the distant shipping noise component has been analyzed with real recording carried out in tropical waters off the west coast of India in the Arabian Sea with bottom mounted transducer at the depth of 30 m from the mean sea level. The study presents the diurnal variation in the ambient noise spectrum over a month with moderate variation in wind conditions. The study primarily focused on the variation due to tide conditions and shipping activity in the nearby port. The broadband spectrum for the frequency bands from 10 to 1600 Hz at 2 Hz resolution has been analyzed.

2. Measurement and processing methodology

The ambient noise data were measured periodically, eight times a day over a period of one month during the winter season (temperature variation from 21 °C to 32 °C) when the sea state (below 2) and wind conditions/variations (below 4 m/s) were moderate [18] and the skies were clear with no rainfall. The seabed is largely soft mud in the area being close to the river mouth. The

* Tel.: +91 832 2558135.
E-mail address: arnabdas1972@hotmail.com

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Table 1
Sensor specifications.

Specification	Description
Hydrophone type	ITC 8264
Sensitivity	−175 dB re 1 μPa
Bandwidth	10 Hz–100 kHz
Beam pattern	Horizontal Omni-directional, ±2 dB Vertical Omni-directional, ±2 dB for upper hemisphere
Self noise	Less than the greater of Knudsen sea state or thermal noise
Gain	6 dB–6 dB + 90 dB in remotely controlled steps of 6 dB
Anti-Aliase Pass Band	Dc to 100 kHz
Sample rate	262144 ks/s, ±2 Hz
Resolution	16 bits
Linearity	ADC only
S/N+ distortion	ADC only

measurement arrangement and the specification of the measuring sensor are given in Table 1. The sea bottom in the area is flat bottom with depth of water approximately 30 m.

The tide information [19] for the area was obtained and the relation of tide height was corroborated with the shipping traffic at the nearby port. The information collected from the local port reveals that the entry/exit of vessels from the port is largely during the high tide as the shipping channel is narrow and shallow restricting movement of vessels during low tide. Further, it was learnt that the port typically handles large cargo vessels that are anchored away from the port and smaller (length 70 m, width 13.5 m and height from keel to deck 4.25 m) self propelled (twin engine of 280 HP) barges carry iron ore from the port to the cargo ships at anchorage. These barges account for the bulk (up to 100 per day) of the traffic in the port. The barges have a very simple machinery configuration with two shafts connected to a four blade propeller that typically rotate at 1800 rpm (30 Hz). The barges being a product of low cost design by local shipyards have poor propeller design and thus have reported excessive cavitation resulting in prominent broadband noise in the radiated noise spectrum [2,17]. The data recording has been carried out periodically from 09:30 h to 17:30 h (GMT + 5:30 h) at an interval of one hour for duration of 2 min. The data is acquired at 256 kHz, filtered and digitized as per the specifications presented in Table 1. Hanning window is used with a data update rate of 5 Hz for the broadband spectrum at frequency resolution of 2 Hz. A 2048 point FFT has been used for computation of the spectrum.

3. Results and discussions

The results of the ambient noise variability in shallow waters off the west coast of India are presented in Figs. 1 and 2 for 2 days (5 January 2010 and 8 January 2010) recording. The conclusions have been drawn based on similar recordings over one month. Ambient noise spectral variation for discrete frequency points (40–1600 Hz at 40 Hz spacing) has been plotted in Figs. 1b and 2 for the fre-

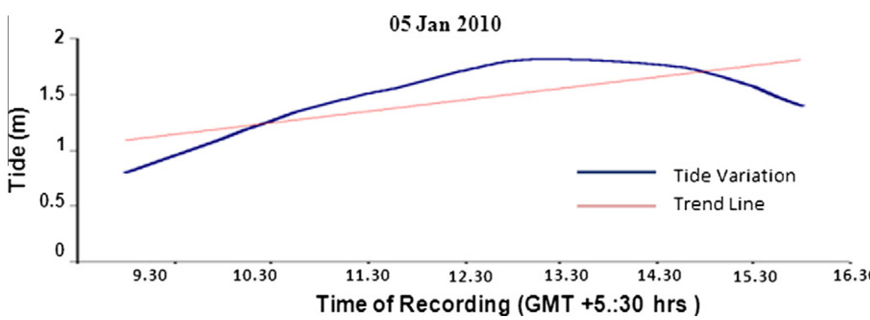

Fig. 1a. Diurnal tidal variation.

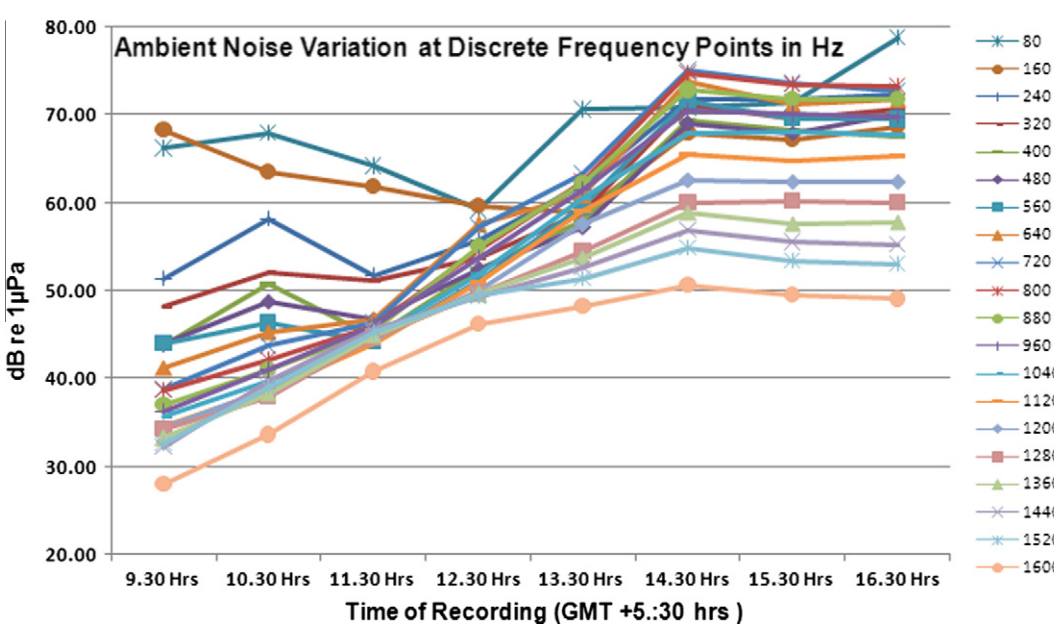

Fig. 1b. Spectral variation at discrete frequency value.

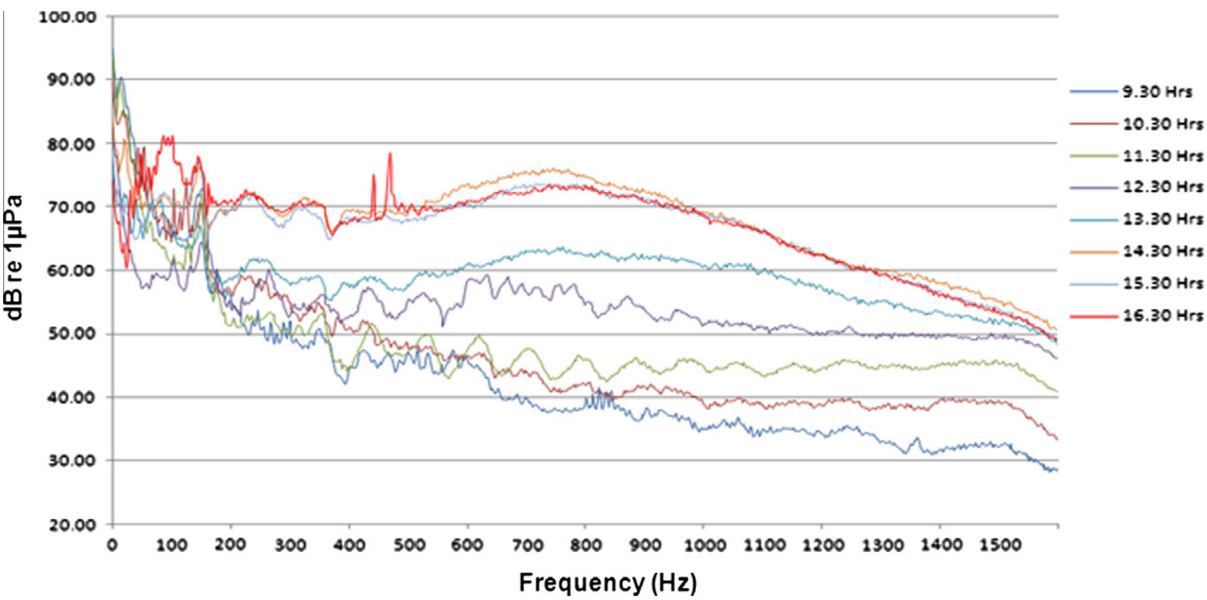

Fig. 1c. Diurnal spectral variation.

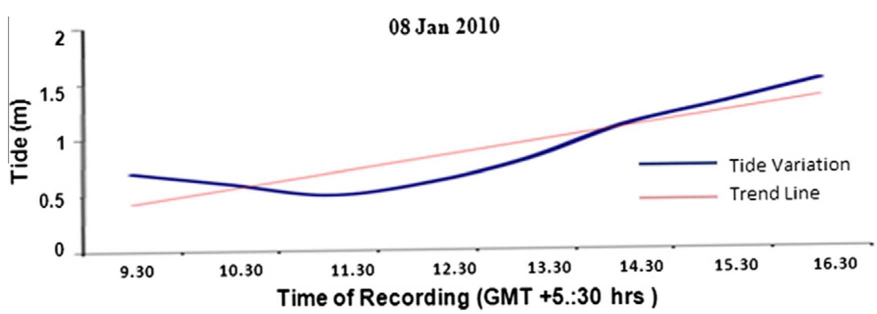

Fig. 2a. Diurnal tidal variation.

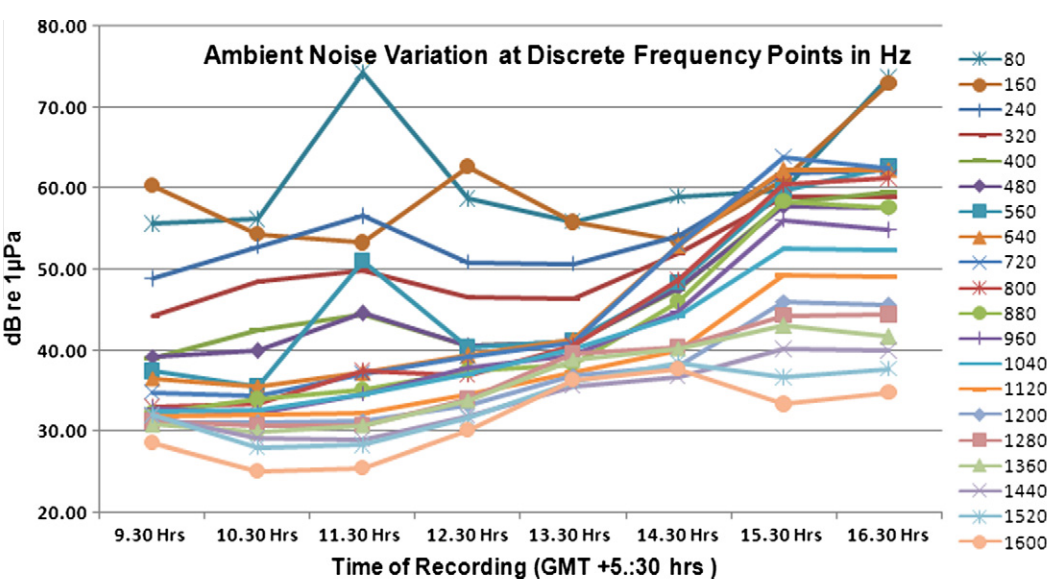

Fig. 2b. Spectral variation at discrete frequency value.

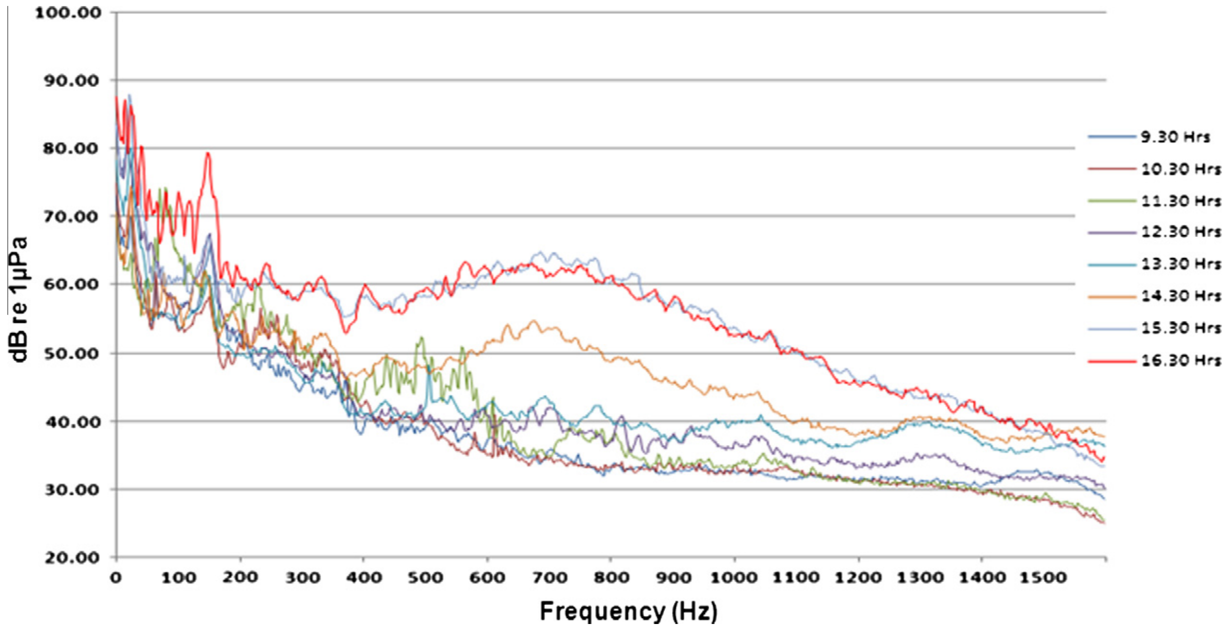

Fig. 2c. Diurnal spectral variation.

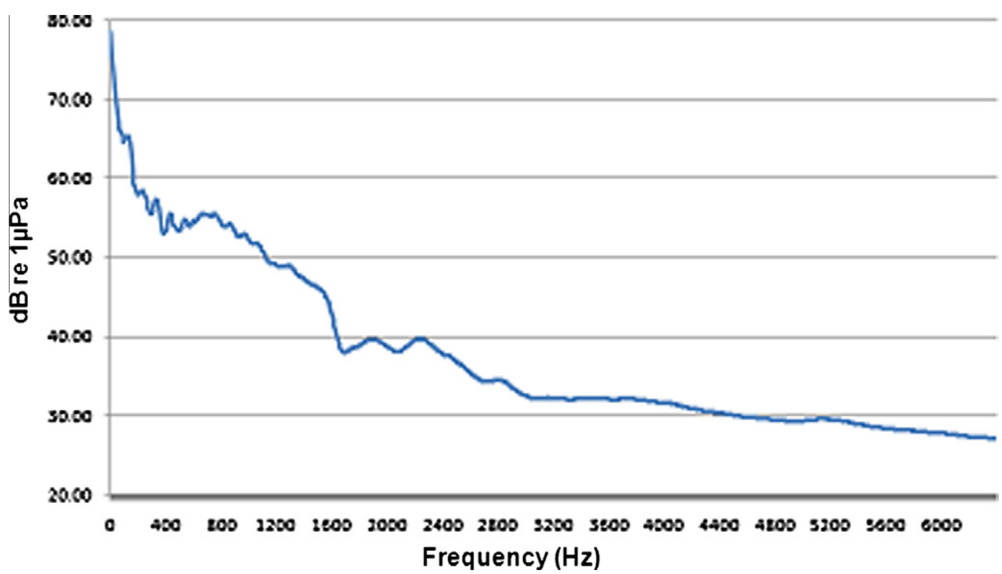

Fig. 3a. Average spectrum across the entire recording duration.

quency band 10–1600 Hz (transducer bandwidth is 10–100 kHz) that covers the peak spectral (Figs. 1c and 2) variation and typically represents the distant shipping noise component of the ambient noise. The tidal variation has been plotted in Figs. 1a and 2a for better appreciation of the dependence of ambient noise levels at discrete frequency values. In the plots it is observed that there is steady rise in the ambient noise spectrum with the tide. In Figs. 1a and 2a, the blue[1] curve represents the actual tide height at the particular recording time and the pink straight line represents the trend of the tide during the day derived from the blue curve. Figs. 3 present the mean and the variance of the average spectrum plot for the entire recording duration.

The variability reported above is attributable to two main reasons. Firstly, the dependence of the shipping activity at the nearby (less than 10 miles) port to the tide variation. Up to, 100 barges are reported to be active during the high tide transporting iron ore from the port to the ships at anchorage. The onboard machineries have been reported to be twin shafts connected to twin engines operating at 1800 rpm corresponding to 30 Hz and connected to the twin shafts at the same speed, that are observed as tonals in the frequency band 60–120 Hz representing shaft rate and blade rate (four blade) combined with the machinery tonals due to the engines. Cavitation inception is very clearly visible in the spectrum plots representing the radiated noise spectrum of a marine vessel. It is important to note that the tide variation also have a profound effect on the propagation of the radiated noise generated by the nearby shipping activity which assumed to largely effect the ambient noise variability [12,13]. At shallow water depths reported in the area the frequency cut-off for the reported depth of 30 m at the hydrophone location for propagating modes is given by c/4d [20], i.e., 12.5 Hz. For 25 Hz, there will be only one dominant mode that satisfies boundary condi-

[1] For interpretation of color in Figs. 1–2, the reader is referred to the web version of this article.

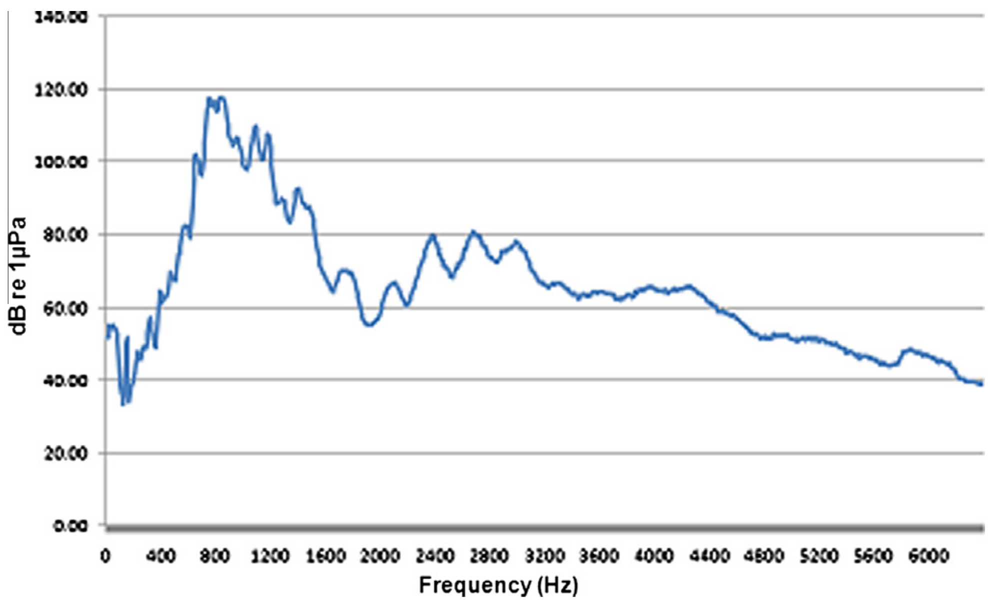

Fig. 3b. Variance of spectrum across the entire recording duration.

tions that will be near-vertical waves and so will encounter several reflections. The grazing angle will be much above the critical angle which also means that there will be high losses on each reflection. This would mean that 25 Hz will be also severely weakened in such a channel. Higher frequencies will propagate better. This is evident in the plots presented in Figs. 1 and 2. The lower frequency values 40–200 Hz are not able to follow the tidal variation curve however; at higher frequencies the ambient noise variation is able to follow the tidal variation curve. This is largely attributable to the fact that at higher frequencies the depth variation up to 1 m can result in more number of modes that propagate and result in up to 35 dB variations in the ambient noise spectral combined with increased shipping activity [20]. The ambient noise curve presented in Figs. 1 and 2, due to distant shipping noise is in line with the plots presented by Urick [2,3].

4. Conclusions

The ambient noise variation in the shallow waters shows a large (up to 35 dB) diurnal variation. It is important to note that these variations are very specific to the location and no generalized patterns could be drawn. The reported work presents the ambient noise variation at the west coast of India in extremely shallow waters (up to 30 m depth) attributed to the heavy shipping activity in the nearby port (less than 10 miles) and the strong propagation dependence to the tidal variation.

Ambient noise variation reported in the literature is largely dependent on the wind and biological noise [3–5,11,14], however the findings in the work are in line with the distant shipping variation reported in shallow water experiments conducted in varying locations [12,13]. This is a limited effort towards ambient noise measurement and analysis reported in the Indian coast related to distant shipping and tidal variation.

The author intends to carry forward the ambient noise study in the same location for wind variation, biological noise dependence, seasonal variations, spatial coherence, stationarity study, etc. with their statistical characterization.

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