Study of Variation in Ambient Noise with Fluctuations of Surface Parameters for the Indian Ocean Region

Piyush Asolkar, Arnab Das, Suhas Gajre and Yashwant Joshi

Abstract Ambient noise variability is a critical challenge encountered by multiple stakeholders, including sonar designers and operators. Among the sources of ambient noise in the ocean, wind related noise has significant impact on sonar performance. The tropical waters in the Indian Ocean Region (IOR), present random fluctuations in the surface parameters, namely the wind speed, surface temperature, wave height, etc. resulting in variations in the ambient noise characteristics. The site-specific surface fluctuations in the tropical regions restrict the possibility of generalized algorithm design to mitigate the ambient noise impact. The work attempts to study the variations in the ambient noise levels corresponding to the fluctuations in the surface parameters. The site-specific behavior of the tropical IOR is demonstrated using surface data available from moored buoy at three distinct locations of the IOR. The analysis methodology can be used to characterize, predict and improve sonar performance, particularly in severe conditions of the tropical IOR.

Keywords Ambient noise characterization · Wind noise · Tropical littoral waters · Indian ocean region · Surface fluctuations · Sonar performance

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1 Introduction

The ambient noise in the oceans has been on the rise and the acoustic systems present sub-optimal performance due to poor Signal to Noise Ratio (SNR) at the deployment location. Modern underwater acoustic systems are largely passive due to their obvious advantages for both military (related to stealth) and also non-military (related to power budgeting in offshore deployments) applications [1]. Hence, the ambient noise becomes a key limitation in improving sonar performance. The ambient noise in the ocean has a multiple source components manifesting at varying frequency bands. Among these ambient sources, the wind noise by far has the maximum impact on the sonar performance due to its overlapping frequency spectrums ranging from 3 kHz up to 5 kHz [2–4].

The different regions, namely the tropical, temperate, and polar present diverse environmental behavior that has direct ramifications on the sea surface parameters and the related wind fluctuations. Further, among them the tropical region displays significant high random diurnal, seasonal and site-specific surface fluctuations namely sea surface temperature, wind speed, wind direction, wave height, current speed and current direction [5]. Thus, the tropical littoral waters of the Indian Ocean Region (IOR) are highly sensitive to the surface disturbances that translate to wind noise [6–10].

The classical SNR enhancement techniques fail to mitigate the noise impact due to random behavior of the ambient noise. However, the understanding of the relation between the measurable surface parameters and the ambient noise can potentially improve our ability to estimate the ambient noise characteristics. Such estimation will facilitate improved mitigation of the wind related ambient noise on sonar performance [11]. Ambient noise measurement and characterization at certain sites have demonstrated high correlation with the surface parameters like wind speed, wave height and sea surface temperature [12–15]. Pioneering work by Knudsen et al. [2] in 1948 had investigated ambient noise variations based on surface parameters and found that ambient noise increases with increasing wind speed and wave height. However, the tropical water of IOR has not been studied that extensively. There are no studies representing site-specific comparison of ambient noise which is the key feature of IOR and is critical for any ambient noise estimation and subsequent SNR enhancement efforts.

The work attempts to study the variations in the ambient noise levels corresponding to the fluctuations in the surface parameters that can be easily measured using Commercially-Off-The-Shelf (COTS) equipment based on available models from the open source literature. Section 2 introduces measurements and ambient noise dependency on surface parameters. Results and site-specific behavior in IOR is demonstrated in Sect. 3.

2 Measurement and Processing Methodology

The data was collected in Arabian Sea off the cost of Goa. Measurements were done periodically eight times a day over a period of 2 month with moderate environmental condition which gives 118 data samples. ITC 8264 omnidirectional hydrophones were used with sensitivity −175 dB re 1 μPa and bandwidth 10 Hz−100 kHz. The data were acquired at rate of 256 kHz filtered and digitized to 16 bits resolution [9]. The site-specific surface data was made available from moored buoy owned by Indian National Centre for Ocean Information Services (INCOISE) at three distinct location of the IOR, namely Arabian Sea, Bay of Bengal and Indian Ocean.

The spectral analysis was carried out using Welch power spectral density [16]. Ambient noise in dB was plotted for different wind speed and wave heights for a frequency range of 10–5000 Hz. Ambient Noise level at different frequencies have been observed for varying wind speed and wave heights. A mathematical model has been designed based on sea surface temperature, wave height, and wind speed. The time series variations of wind speed and wave heights from three distinct sites from IOR namely Arabian Sea, Indian Ocean and Bay of Bengal are analyzed for a yearly data. Wind–wave relationship of the three sites was observed by plotting wind speed against wave height. Ambient noise levels at three sites were compared based on modeled data.

3 Results and Discussions

The results of ambient noise variation with wind speed and wave height are presented in Figs. 1 and 2. Measurements showing dominant evidence of noise from ship (46 samples) were not included in analysis. Figure 1 shows ambient noise variation with respect to variation of wind speed over the spectrum of 10–5000 Hz. It is observed that noise level increases with the increase in wind speed. The frequency spectrum up to 500 Hz shows less variation with respect to wind speed.

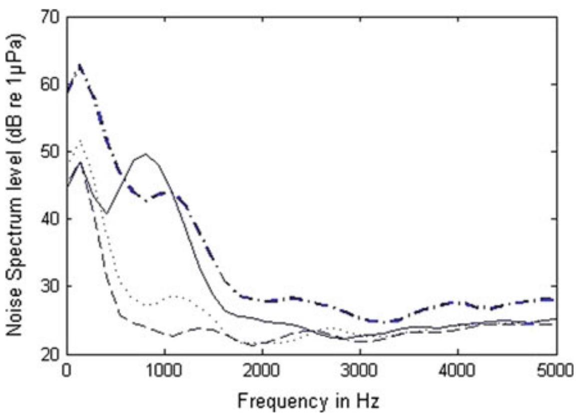

Fig. 1 Ambient noise spectrum for wind speed of 1 m/s (*dotted line*), 2 m/s (*dashed line*), 3 m/s (*solid line*) and 4 m/s (*dash-dot line*)

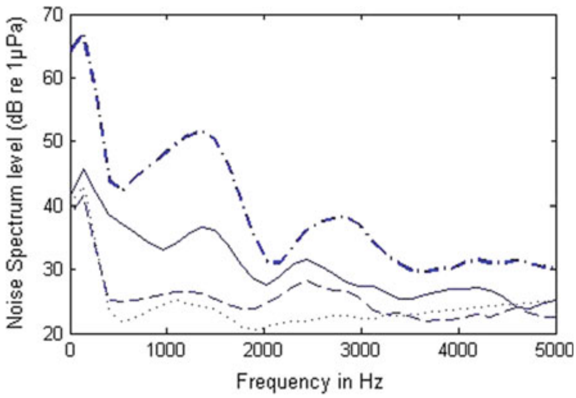

Fig. 2 Ambient noise spectrum for 0.5 m (*dotted line*), 1 m (*dash line*), 1.5 m (*solid line*) and 2.1 m (*dash-dot line*) wave heights

However, spectrum of 500–4500 Hz shows higher dependency on wind speed. Spectrum follows Knudsen [2] spectra with a decreasing slope of 6 dB per octave for a frequency range of 100–5000 Hz. It shows higher noise level and slope up to 1 kHz, however, slope decreases with increase in frequency representing weak dependency of ambient noise due to wind at higher frequency. Figure 2 shows ambient noise variation with respect to wave height over spectrum of 10–5000 Hz. A peak is observed at a low frequency of 70–100 Hz which is due to turbulence. Wide variations between 1000–5000 Hz are mainly due to bubbles and spray. Noise due to bubbles show higher variations with increase in wave height [17, 18]. It shows a decreasing slope of 11 dB/octave for frequency band of 10–5000 Hz. Higher slope at frequency of 1–3 kHz clearly represents the higher variation of noise level due to wave height, bubbles and spray [17].

This analysis represents high correlation of ambient noise with wind speed and wave height. Ambient noise model have been designed based on nonlinear regression analysis given by Eq. 1.

$$NL = a + b * \log_{10}(W_s) + c * \log_{10}(\mathrm{SST}) + d * W_h^2 + e * W_h \quad (1)$$

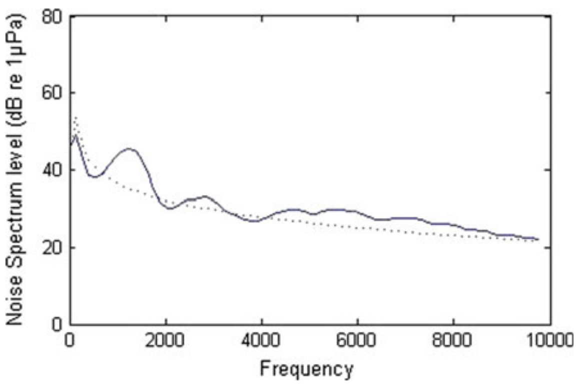

Fig. 3 Comparison of field (*solid line*) and modeled (*dotted line*) spectra

where, *NL* is noise level, W_s is wind speed, W_h is wave height and *a*–*e* are the regression coefficients.

Figure 3 shows comparison of field measurements with modeled results. It shows that predicted values by the model are close to the measured ambient noise value.

3.1 Comparison of Field Environments

Indian Ocean Region is well-known for the random fluctuation of the environment; hence generalized mitigation algorithm fails in IOR. In order to design efficient mitigation methods it is necessary to analyze dependency of physical parameters and their effect on ambient noise. Sea surface data from moored buoy (owned by INCOISE) at three distinct sites namely Arabian Sea, Indian Ocean, and Bay of Bengal is used for analysis of the relation between surface parameters in IOR. Figure 4 shows time series variation of sea surface temperature, wind speed and

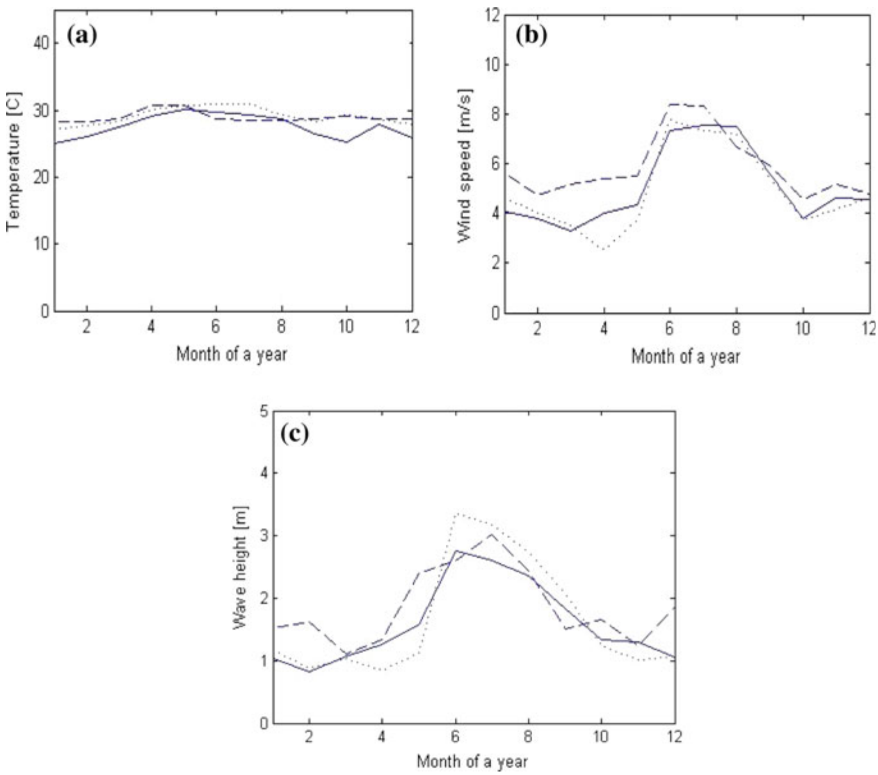

Fig. 4 Time series plot of **a** sea surface temperature, **b** wind speed and **c** wave height for Arabian Sea (*dotted line*), Indian Ocean (*solid line*) and Bay of Bengal (*dash line*)

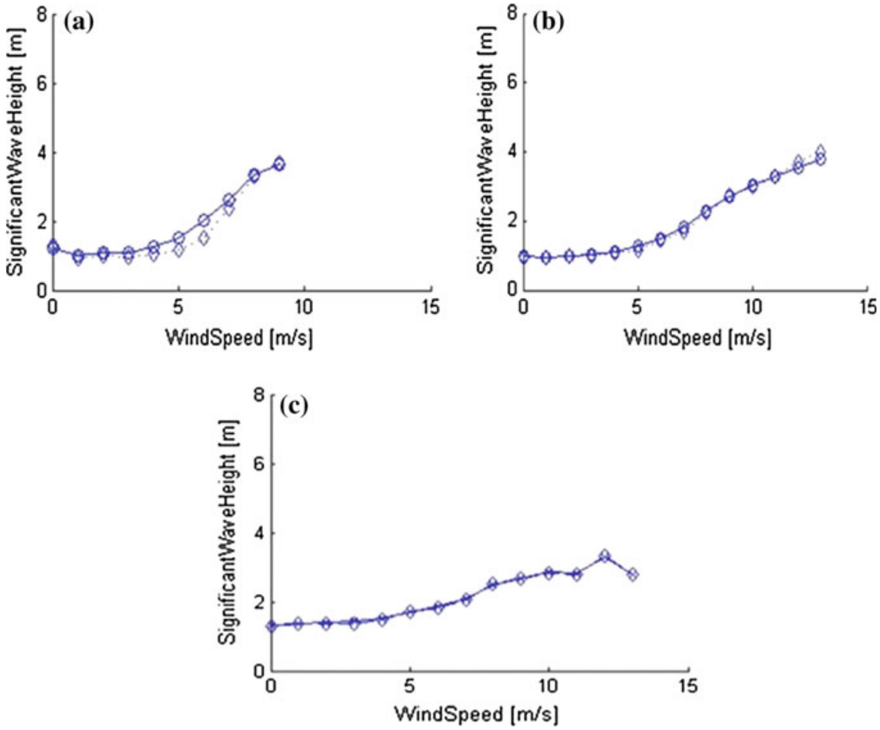

Fig. 5 Wind speed–wave height scatter plot for **a** Arabian Sea, **b** Indian Ocean, **c** Bay of Bengal

wave height over a period of year. Monthly average values of parameters are considered for plots, however, diurnal variations over the year are considered for scatterplot.

The correlation between wind speed and wave height can be analyzed based on scatter plot between wind speed and wave height. Wind–wave relationship for the three sites is shown in Fig. 5, where it is observed that it follows similar relationship proposed by Barth et al. [19] despite the range of wind speed and wave height is different, the relationship can be observed based on mean of scatter plots.

As all the sites in consideration follows similar wind–wave relationship, it follows similar physical phenomenon however time series fluctuations are severe for Arabian Sea. Ambient noise model was evaluated for three sites and corresponding results are shown in Fig. 6.

Figure 6 shows that ambient noise levels are higher in the month of June, July, August as it's the period of monsoon. Increase in ambient noise in this period is due to high tides and bubble noise because of rain. Ambient noise level in Bay of Bengal is 10 dB higher as compare to Indian Ocean and Arabian Sea, however diurnal and seasonal ambient noise fluctuations are higher in Arabian Sea. Figure 7a–c shows relationship of normalized variance of sea surface temperature,

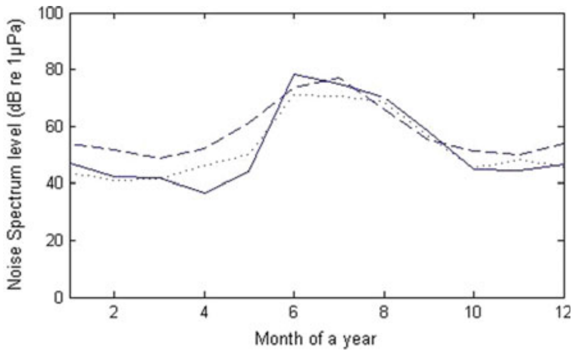

Fig. 6 Modeled ambient noise for Arabian Sea (*solid line*), Indian Ocean (*dotted line*) and Bay of Bengal (*dash line*)

variance of wave height, and variance of wind speed for IOR. Figure 7d compares the variance of ambient noise for IOR.

Variance of ambient noise with respect to surface parameters at different sites of IOR can be observed in Fig. 7. Where it is observed that ambient noise level is highly correlated to wind speed and wave height, however variance of surface parameters is site-specific, which results in site-specific variance of Noise level (Fig. 7d).

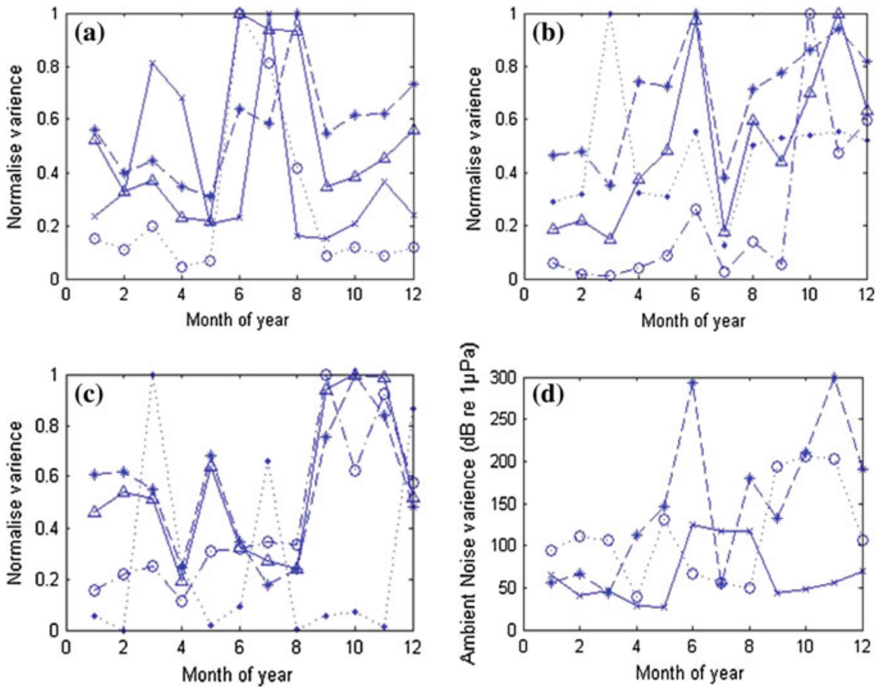

Fig. 7 Comparison of variance of SST (*dot line*), wind speed (*dash line*), wave height (*dash dot line*) and ambient noise (*solid line*) for **a** Arabian Sea, **b** IOR, **c** Bay of Bengal. **d** Comparison of variance of ambient noise for Arabian Sea, (*solid line*), IOR (*dash line*), Bay of Bengal (*dotted line*)

4 Conclusions

Various studies have shown that ambient noise is highly correlated with sea surface parameters like wind speed, wave height, sea surface temperature; however, it shows wide variations with time and site. In this work, ambient noise variations are observed with respect to surface parameters at Arabian Sea. The analysis shows that ambient noise level increases with increase in wind speed and wave height. Ambient noise variations at different frequencies have been observed for range of wind speed and wave height it shows higher noise levels at 1 kHz frequency which may be due to bubbles and spray. Ambient noise model have been verified with field data and found to be efficient for ambient noise analysis. Sea surface parameter fluctuations at three sites of IOR have been analyzed and ambient noise variations are plotted based on monthly average sea surface parameters for three sites which shows seasonal variation of ambient noise in IOR. It shows remarkable fluctuations in ambient noise level. This is the first such effort to compare seasonal variation of ambient noise in different regions of IOR. However it can be further improved by improving ambient noise model using real-time data with wide variation of sea surface parameter. The analysis methodology can be used to characterize, predict and improve sonar performance, particularly in severe conditions of the surface fluctuations in the tropical IOR.

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References

1. Nair N.R., Elizabeth S.N., Raju R.P.: Underwater Ambient Noise Variability from Satellite data–An Indian Ocean perspective. Underwater Technology (UT) IEEE, (2015).
2. Knudsen V.O., Alford R.S., Emling J.W.: Underwater Ambient Noise. J. of Marine research vol 7 pp. 410–429 (1948).
3. Dahl P.H., Miller J.H., Cato D.H., Andrew R.K.: Underwater Ambient Noise. Acoust. Today, vol. 3, pp. 23–33 (2007).
4. Wenz G.M.: Acoustic Ambient Noise in Ocean:Spectra and Sources. J. Acou. Soc. of America (1962).
5. Graham N.E., Barnett T.P.: Sea-Surface Temperature, Surface Wind Divergence and Convection over Tropical Oceans. Science J. 238, pp. 657–659 (1987).
6. Ramji S., Latha G., Rajendran V., Ramakrishnan S.: Wind Dependence of Ambient Noise in Shallow Water of Bay of Bengal. Appl. Acoust., vol. 69, pp. 1294–1298 (2008).
7. Najeem S., Sanjana M.C., Latha G., Durai P.: Wind Induced Ambient Noise Modelling and Comparison with Field Measurements in Arabian Sea. Appl. Acoust., vol. 89, pp. 101–106 (2015).
8. Vijayabaskar R.V.: Analysis and Modeling of Wind Dependence of Ambient Noise in Shallow Water of Arabian Sea. Eur. J. Sci. Res., vol. 50, no. 1, pp. 28–34, (2011).
9. Das A.: Shallow Ambient Noise Variability due to Distant Shipping Noise and Tide. Appl. Acoust. vol. 72, pp. 660–664, (2011).

10. Murugan S.S., Natarajan V., Kumar R.R.: Noise Model Analysis and Estimation of Effect due to Wind Driven Ambient Noise in Shallow Water. Int. J. Oceanogr., vol. 2011, pp. 1–4, (2011).
11. Peyvandi H., Farrokhrooz M., Roufarshbaf H., Park S.J.: SONAR Systems and Underwater Signal Processing: Classic and Modern Approaches. Intech Open access publisher, (2011).
12. Roth E.H., Hildebrand J.A., Wiggins S.M., Ross D.: Underwater Ambient Noise on the Chukchi Sea continental slope from 2006–2009. J. Acoust. Soc. Am., vol. 131, no.1, pp. 104–108, (2012).
13. Jung S.K., Choi B.K., Kim B.C., Kim B.N, Kim S.H., Park Y., Lee Y.K.: Seawater Temperature and Wind Speed Dependences and Diurnal Variation of Ambient Noise at the Snapping Shrimp Colony in Shallow Water of Southern Sea of Korea J. J. Appl. Phys., vol. 51, pp. 12–14, (2012),
14. Kim B., Hahn J., Choi B.K.: Wind Dependence of Oceanic Ambient Noise Measured at the Ieado Ocean Research Station Proceeging Symp. Ultrason. Electron., vol. 31, pp. 411–412, (2010).
15. Poikonen A.: Measurements, Analysis and Modeling of Wind Driven Ambient Noise in Shallow Brackish Water (2012).
16. Welch P.D.: The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method based on Time Averaging over Short, Modified Periodograms. IEEE Trans. Audio and electroacoust. Au-15 pp 70–73, (1967).
17. Harland E.J., Jones S.A., Clarke T.: SEA 6 Technical Report: Underwater Ambient Noise. Report by QINETIQ (2005).
18. Harland E.J., Richards S.D.: SEA 7 Technical Report: Underwater Ambient Noise. Report by QINETIQ (2006).
19. Barth S., Eecen P.J.: Description of the Relation of Wind, Wave and Current Characteristics at the Offshore Wind Farm Egmond aan Zee (OWEZ) Location in 2006. Report by ECN (2012).