An investigation on the Fluctuation and variability of ambient noise in shallow waters of south west Bay of Bengal

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Variability of ambient noise in shallow south west Bay of Bengal is investigated in the band 0.5 - 5.0 kHz using time series measurements during Sept-Nov 2010. Data is segregated into southwest, transition and northeast monsoon on the basis of seasons. Variability of Noise Level (NL) at the site is mainly influenced by wind, shipping and biological activity along with precipitation (during transition and northeast monsoon). NL increases and generates broadband peaks in the band 2-4 kHz due to heavy precipitation. In general, average NL increases as the season progresses from southwest to northeast through transition period. But the variability in NL, reported in terms of Standard Deviation (SD) \( \sigma \), is high during transition (due to passage of tropical cyclones), followed by southwest and northeast period. SD decreases with increase in Beaufort (Bft), with \( \sigma \) of <2.50 dB for frequency >2.0 kHz for 5 Bft. The observed NL is compared with standard wind generated noise spectra.

[Keywords: Ambient noise; Fluctuation; Shallow waters]

Introduction

The underwater ambient noise in shallow Ocean is well known for its variability. The variability can be expressed in terms of fluctuation spectrum which gives the fluctuation spectra per unit frequency band as a function of frequency. Main components of ambient noise spectrum are (i) sea surface noise: usually wind-dependent noise and rain noise; (ii) biological noise: the noise is caused by variety of underwater animals like whales, fish etc; and (iii) ship noise: result of near-by and distant shipping traffic activities. It is evident that the action of wind and rain on sea surface make up an important natural source of sound, which is dominating all others over by a wide range of frequencies. In the frequency range from 0.2-50 kHz, naturally generated sound at the sea surface is predominantly produced by wind-driven breaking waves and precipitation. Sound generated by wind has a distinctive shape, but is relatively quiet when compared to the sound generated by rain as sound of heavy rain is very, very higher by~10dB. The slope of the rain spectra is not as steep as wind generated and can be distinguished from each other by examining the slope and shape of underwater sound spectrum. Coastal regions with heavy shipping can have ambient noise background with noise level (~10 dB) higher than wind – wave noise. Piggott observed the shallow water ambient noise measurements on the Scotian shelf at 20–28 fathom water depths and found that the spectral energy distribution was wind dependent at high frequencies and there is a seasonal variation in noise level which is independent of frequency. Recent studies by Hazen on seasonal dependence of shallow water ambient noise reported that the average noise level in summer was lower than in other seasons. Similar study on ambient noise spectra by Walkinshaw observed the correlation between wind speed and ambient noise at low frequency range. It was noticed that the average noise level during summer was 5 dB lower than winter due to seasonal changes in sound propagation. Ambient noise level and propagation loss are the two
primary environmental acoustic conditions which are characterized by the site dependence in shallow waters\textsuperscript{10}. In shallow water the speed of the sound and the bottom properties vary to a large extent with location\textsuperscript{11}. During the period of passing storms, noticeable day to day variations are present in the high and low frequencies\textsuperscript{12}. This is because time periods of fluctuations in noise level corresponds to changes in local weather patterns\textsuperscript{13}. Monsoon season is always characterized by the presence of showers from drizzle to heavy rain accompanied by high wind. In heavy rainfall large rain drops of size 10 – 30 mm/hr is present and their sound can be clearly noticed within the frequency band of 2 – 8 kHz\textsuperscript{4}. Variability in ambient noise from periodical measurements for wind generated noise in shallow waters of Bay of Bengal has been studied by Ramji et. al.\textsuperscript{14,15}. Main purpose of this paper is to study the widespread variability in spectrum level and content of shallow water ambient noise in south west Bay of Bengal, with the passage of seasons.

**Materials and Methods**

An automated sub-surface noise measurement system was deployed at 11°41.018’N, 79°53.949’E in shallow water of southwest Bay of Bengal (Fig. 1) at 32 m ocean depth during the period of Sept- Nov 2010. Sub-surface system comprises of vertical linear array of omnidirectional hydrophones with data acquisition modules. Sampling frequency of the data acquisition system was set to 50 kHz. Sampling interval was set to 3 hours with data recording duration to be 30s. Hence eight samples of data acquired per day.

Data from hydrophone (0.1 - 10 kHz) at the mid water column is considered for analysis. Noise due to surface disturbances and animate and inanimate beings at the bottom can be measured effectively if an omnidirectional hydrophone is placed at the middle of the vertical column. A fundamental measurement that can be obtained by hydrophone is the spatially filtered average of the noise over an area of the shallow water surface\textsuperscript{16}. This enables the detection of individual events and great variability in spectral structure can be observed\textsuperscript{16}.

Array of hydrophones sense acoustic pressure fluctuation due to various sources of noise which translates into electrical signals and then logged by the data acquisition system. Recorded voltage is then converted to units of µPa by applying pre amplifier gain and receiving sensitivity of the hydrophone. Power level of the noise spectrum enables us in detection and classification of signals buried in the noise. Welch’s method of averaged periodgrams was used to calculate the noise level spectrum. Multiple spectra are obtained first by segmenting data into smaller portions, windowed with a Hamming window, and fast fourier transformed with 50% overlap. Spectra are then averaged to obtain the final spectrum. Spectrum was computed every 24.414 Hz bins so that slight variations can be studied. Wind data at the ocean surface was recorded using wind data logger.

**Results and Discussion**

Temporal variability in ambient noise has been investigated using three months of time series measurements (September - November), representing three different weather conditions southwest (SW) monsoon, transition of monsoon and northeast (NE) monsoon respectively. Noise characteristics during each period are discussed separately below.
Data recorded during 2nd - 30th September 2010 (226 records) has been used for the fluctuation analysis in the band 0.5 - 5.0 kHz. This period represents comparatively fair weather period with no cyclones and minor precipitation events. Time series of noise level data were plotted and it shows that NL ranges from 90-49 dB within the frequency range of 0.5- 5.0 kHz (Fig. 2). Fluctuation in NL is more pronounced in the band of 0.5- 3.0 kHz. Specific peaks of biological origin have been identified in the low frequency end, as indicated by arrows in Fig.2, due to fish species like drummers and croakers, which are abundant in shallow southwest Bay of Bengal. Averaged noise level (NL) for the 226 records varies from ~65.71 dB at 0.5 kHz to ~57.69 dB at 5.0 kHz (Fig. 4). Statistical analysis of the noise samples averaged over longer time periods have been commonly reported in terms of the standard deviation (SD), σ, of the measured NL. SD in the frequency band 0.5-5.0 kHz is shown in Table 1. SD of noise varies from ~6.40 to ~6.60 dB at 0.5 kHz and 1 kHz respectively and gradually decreases to ~2.30 dB at 5.0 kHz (Table 1). The entire data set is segregated into different Bft scale after removing data with shipping and biological interference and the estimated average noise level and standard deviation is shown in Fig. 5 and 6. Considering different wind forcing (Bft 1-5), σ values decreases with increasing Bft number. Within the Beaufort (Bft) wind force scale 1-5, SD ranges from 6.44-5.40 dB and 2.03-0.79 dB for 0.5 kHz and 5.0 kHz respectively. Lesser variability of ‘σ’ of < 2.05 dB is seen for frequencies > 2.5 kHz for high wind force of Bft 5 (Fig. 6a). Thus at higher frequencies (>2.5 kHz) the noise level and high wind speed is consistent when wind noise is dominant.

According to the India Meteorological Department (IMD), the month of October represents the transition of monsoon wherein the SW monsoon changes into a northeast wind field. By early October, variable winds are frequent with the formation of thunderstorm, tropical depressions and cyclones. As per the information regarding cyclonic disturbances formed over the Bay of Bengal provided by the IMD,

<table>
<thead>
<tr>
<th>Frequency(kHz)</th>
<th>'σ' in noise level(dB)-SW monsoon</th>
<th>'σ' in noise level(dB)-Transition of monsoon</th>
<th>'σ' in noise level(dB)-NE monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>6.39</td>
<td>7.56</td>
<td>5.30</td>
</tr>
<tr>
<td>1.0</td>
<td>6.63</td>
<td>7.86</td>
<td>5.55</td>
</tr>
<tr>
<td>1.5</td>
<td>5.80</td>
<td>7.45</td>
<td>4.68</td>
</tr>
<tr>
<td>2.0</td>
<td>4.92</td>
<td>6.57</td>
<td>4.49</td>
</tr>
<tr>
<td>2.5</td>
<td>4.17</td>
<td>5.56</td>
<td>4.40</td>
</tr>
<tr>
<td>3.0</td>
<td>3.70</td>
<td>5.15</td>
<td>5.08</td>
</tr>
<tr>
<td>3.5</td>
<td>3.33</td>
<td>4.99</td>
<td>4.80</td>
</tr>
<tr>
<td>4.0</td>
<td>2.96</td>
<td>4.58</td>
<td>3.82</td>
</tr>
<tr>
<td>4.5</td>
<td>2.54</td>
<td>4.18</td>
<td>3.80</td>
</tr>
<tr>
<td>5.0</td>
<td>2.32</td>
<td>3.71</td>
<td>3.46</td>
</tr>
</tbody>
</table>
Averaged out noise level (NL) for the 247 records varies from ~66.56 dB at 0.5 kHz to ~60.70 dB at 5.0 kHz (Fig. 4). SD for the frequency range from 0.5-5.0 kHz is shown in Table 1. SD in noise level varies from ~7.56 dB at 0.5 kHz; increases up to ~7.90 dB at 1.0 kHz then decreases ~3.70 dB at high frequency. Variability in SD of noise level is high compared to south west period because of frequency of tropical cyclones as well as high intermittent showers. SD ranges from 8.00 - 3.06 dB and 6.56-1.66 dB for 0.5 and 5.0 kHz respectively within the Bft wind force scale 1-5. Considering different Bft scales, $\sigma$ values decreases with increasing Bft number and a lesser variability of ‘$\sigma$’ <2.21 dB is seen in this frequency band for high wind force of Bft 5 (Fig. 6b).

During NE monsoon the wind field reverses and experiences major rainfall activity with heavy showers over southern peninsular of India. As per IMD information, during 2010, NE monsoon rainfall was activated on 29th October and severe cyclonic storm ‘JAL’ was present from 4th - 8th November. Data recorded during 1st to 31st October 2010 (247 records) is used for the study. Time series of noise level were plotted and it shows that NL ranges from 94-51 dB within the frequency range of 0.5-5.0 kHz (Fig. 2). The variability of noise level is high due to the passage of tropical cyclones. Here also, the fluctuation in NL is more pronounced in the band of 0.5 kHz-3.0 kHz (Fig. 3) and decreases with increase in frequency. Broad band peaks are noticed in the high frequency band due to the intermittent showers and heavy rainfall. Averaged out noise level (NL) for the 247 records varies from ~73.88 dB at 0.5 kHz to ~62.25 dB at 5.0 kHz; increases up to ~7.90 dB at 1.0 kHz then decreases ~3.70 dB at high frequency. Variability in SD of noise level is high compared to south west period because of frequency of tropical cyclones as well as high intermittent showers. SD ranges from 8.00 - 3.06 dB and 6.56-1.66 dB for 0.5 and 5.0 kHz respectively within the Bft wind force scale 1-5. Considering different Bft scales, $\sigma$ values decreases with increasing Bft number and a lesser variability of ‘$\sigma$’ <2.21 dB is seen in this frequency band for high wind force of Bft 5 (Fig. 6b).
varies from ~5.30 to ~5.60 at 0.5 kHz and 1.0 kHz for low frequencies which declines ~3.46 at 5.0 kHz for higher frequencies (Table 1).

Wind speed has been incorporated to enable comparison with noise spectrum (Fig. 2). On comparing the noise level with wind speed, good correlation is noticed during September and October. By November, the correlation decreases due to the onset of monsoon, and since the noise has rain components also.

Comparison with other shallow water sites

In the international scenario, shallow water ambient noise measurements have been collected on the New Jersey continental shelf24, two regions of Australia i.e. Spencer Gulf (South of Australia) and off Perth (West of Australia)25 and Continental shelf break off south china26 etc. Off the New Jersey continental shelf measurements have been carried out in the frequency range from 0.05-3.0 kHz and exhibited an average noise level of 58-68 dB during the period of tropical storm for wind speed of about 9-21knots. Ambient noise levels are seen to be well correlated with wind speed and there is a 10dB difference in noise level within the frequency band from 0.05-3.0 kHz. On comparison with our observation in the frequency range from 0.5-5.0 kHz, the average noise level was 60-72 dB during rough weather condition and showed dependency on same wind speed condition (9-20 knots). 12 dB difference noise level in the frequency band from 0.5-5.0 kHz.

In shallow waters of Australia also good correlation is observed in noise level with local wind speed. During normal weather condition the average noise level is about 62dB at 0.5 kHz as a function of local wind speed of about 4 m/s where as the difference of about 3 dB average noise level was observed in our location i.e. about 65 dB at 0.5 kHz on same wind speed condition.

In ASIAEX (Asian Seas International Acoustics Experiment) off south china sea measurements were carried out in the low frequency band and the SD of noise level is about 3-4 dB in the frequency band from 0.05-1.2 kHz whereas in comparison with our observation there is 1 dB difference in SD of noise level i.e. 4-5 dB in the frequency range from 0.5 -1.5 kHz.

Comparison of observed spectra with standard wind generated noise spectra

The average noise levels during southwest and transition of monsoon have been compared with Knudsen curves3 in the frequency band 1 - 5 kHz for Bft scales 2 to 5 (Fig. 5). Bft 1 is not considered because wind influence of ambient noise in shallow waters occurs for wind speeds above 2.5  m/s only as per literature14. Also, in the frequency band <1 kHz there is a possibility of interference from shipping.
and hence not considered. For 2 and 3 Bft, the noise level exhibits an increase of 1-6 dB at the low frequency end and 6-10 dB at the high frequency end. For Bft 4 and 5, the noise level at the site is higher than Knudsen curves by 0-2 dB and 6-7 dB at 1 kHz and 5 kHz respectively. Overall increase in noise level can be attributed to the multipath propagation at the extremely shallow measurement location. Difference in noise level in the band for different Bft is given in Table 2.

**Conclusion**

Period considered for the study depicts seasonal changes that influences the ambient noise field and hence is useful for arriving at an estimate in noise spectrum level and content. Lower average noise level is observed during SW monsoon (~70 to ~58 dB) owing to the calm weather conditions at the site, followed by transition period (~74 to ~60 dB) when cyclones started forming in the Bay, and subsequently NE monsoon (~76 to ~62 dB) which causes heavy showers in this part of the country contrary to summer monsoon. In all cases, σ shows a decreasing trend with increasing frequency, with highest σ during transition and lowest σ during SW monsoon. SD (σ) is high during transition of monsoon (~7.60 dB at 0.5 kHz and ~7.90 dB at 1.0 kHz) due to frequency of passage of tropical cyclones, storms, changing of monsoon wind field and dominant coastal shipping activities. During NE monsoon, variability in noise level is high in the 2-4 kHz band due to the presence of heavy precipitation and rainfall which generates the noise level peaks at 2-4 kHz. ‘σ’ computed for different Bft wind force scales, for SW and transition period shows that σ decreases with increase in Bft and σ <2.50 dB is seen in this frequency band > 2.0 kHz for high wind force of Bft 5. Observed NL is higher than standard wind generated noise spectra, due to the waveguide nature and multiple reflections

**Table 2–Difference in noise level in the band for different Bft.**

<table>
<thead>
<tr>
<th>Bft Scale</th>
<th>Knudsen</th>
<th>SW monsoon</th>
<th>Transition of monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>55-44</td>
<td>61-54</td>
<td>62-56</td>
</tr>
<tr>
<td>3</td>
<td>61-49</td>
<td>62-56</td>
<td>64-58</td>
</tr>
<tr>
<td>4</td>
<td>64-52</td>
<td>64-57</td>
<td>66-59</td>
</tr>
<tr>
<td>5</td>
<td>66-55</td>
<td>66-59</td>
<td>68-61</td>
</tr>
</tbody>
</table>

**Fig.6–Standard deviation (σ) of noise level in different Beaufort during (a) SW monsoon (b) transition of monsoon.**
at this very shallow environment. Changing of monsoon wind field, intermittent showers, heavy convective precipitation with passage of cyclones are the main key factors for the observed trend in variability which is evident from the measurements.

Acknowledgements

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References

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