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Comprehensive correlation of ocean ambient noise with sea surface parameters

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ABSTRACT

Ambient noise variability is a critical aspect for the sub-optimal performance of sonar systems. The sea surface parameters (SSP) like wind speed, sea surface temperature and wave height are known to be dominant factors responsible for ambient noise levels and their variability is a major challenge in designing noise mitigation algorithms. Variability across three regions namely tropical, temperate and polar region is significant and quantification of these random fluctuations could potentially facilitate signal processing algorithms to enhance signal to noise ratio. This work presents comprehensive statistical analysis of the spatio-temporal variations of these SSP across three regions and correlates their impact on ambient noise in the specific region. Fluctuations in the tropical region are significant and do justify the challenges for effective sonar design in the region. Analysis has been done on SSP data available in open source collected by ocean observatories deployed at designated sites. Real experimental ambient noise data recordings in tropical littoral waters of the west coast of India and open source acoustic data from other regions have been used to validate the proposed analysis. Understanding of the statistical variability of SSP and its correlation with ambient noise may improve modeling efforts and design generalized mitigation strategy.

1. Introduction

The sea surface parameters change drastically from the poles to the equator (Nasa, 2017), which has a significant impact on underwater acoustics and the ambient noise in the region (Nicholas et al., 2002; Ainsley, 2010). Ambient noise variability due to spatiotemporal variations of sea surface parameter is a challenge for ensuring optimum performance of underwater systems at the deployment locations (Knudsen et al., 1948). These site-specific fluctuations of ocean parameters in the tropical, temperate and polar ocean restrict the possibility of generalized strategy to mitigate the ambient noise impact. The tropical shallow waters present even higher ambient noise variability due to significantly high diurnal, seasonal and site-specific fluctuations of Sea Surface Parameters (SSP), namely Sea Surface Temperature (SST), wind speed and wave height.

Since the pioneering work by Knudsen et al. (1948) various studies have been proposed representing ambient noise variation triggered by natural physical processes, marine life and human activities (Wenz, 1971; Urick, 1983; Harland et al., 2005; Harland and Richards, 2006). Beyond this several inverse sensing studies have been proposed presenting estimation of environmental conditions such as wind speed, rain, etc., based on underwater acoustic recordings, indicating strong interaction between surface parameters and ambient noise (Nystuen et al., 2015; Pensieri et al., 2015). In the absence of sound from human activities and marine life, ambient noise levels are mainly generated due to sea surface activities related to wind and wave (Harland et al., 2005, Harland and Richards, 2006). Studies show that wind noise is dominant in the spectral band of 500 Hz to 25 kHz and noise level increases with increasing wind speed and wave height. Detailed studies show, diverse environmental conditions in different regions of the earth that result in deviation of ambient noise level and corresponding spectral characteristics (Harland et al., 2005, Harland and Richards, 2006; Das, 2011; Asolkar et al., 2016; Ramji et al., 2008; Najeem et al., 2015). Hence, it becomes necessary to analyze region specific comparison of ambient noise and SSP, which is critical for any ambient noise estimation and subsequent SNR enhancement efforts. The acoustic data used for analysis had variable sampling frequencies for different data sets with minimum sampling rate of 16384 Hz. Thus, the ambient noise analysis in this work has been limited to 8 kHz.

Various studies available based on open source satellite and moored buoy data present distribution of SSP for different regions (Etter, 2009; Asolkar et al., 2016; Wallace et al., 1989; O'Neill et al., 2010; Chu,

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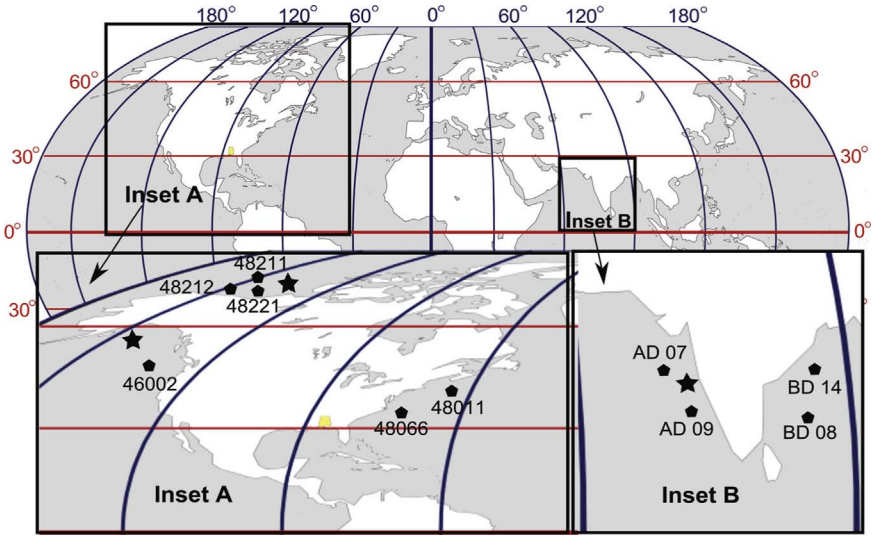

Fig. 1. Data measurement locations. (*Star represents Acoustic data location and pentagon represents SSP buoy location.*). Note: Map not to scale, for representative purpose only.

1989; INCOISE, 2017; NOAA, 2017). Analysis of SST shows prominent three bands with maximum temperature in the tropical region and minimum in the polar region. Tropical regions show higher SST time series anomaly which translates to corresponding higher wind speed and wave height anomaly as compare to temperate and polar regions. Various studies have been presented in the literature elaborating the role of wind speed and wave height in noise generation (Marsh, 1963; Piggott, 1964). The SST shows a linear relationship with wind speed (Wallace et al., 1989; O'Neill et al., 2010; Chu, 1989) and hence SST can be analyzed for the early estimation of wind noise. However, the delay in ambient noise and SST varies with regions that need to be accounted for (Asolkar et al., 2016). Wind speed and Wave height anomaly is observed to be directly related to the variation of the ambient noise characteristics and needs to be analyzed regionwise.

This work attempts to compare the spatial distribution of ambient noise due to sea surface activities in the three regions to understand the diversity in the global ambient noise characteristics. Spatiotemporal mapping of ambient noise due to the corresponding variation of SSP is a critical challenge which can be achieved based on time series analysis along with statistical comparison based on 3D plots of SSP at different buoy locations. Different descriptive statistics like time series analysis and probability density function (pdf) have been used to present the characteristic differences between SSP for the three regions. The impact of the SSP on ambient noise has been discussed in order to understand the ambient noise generation process and the possibility of precise estimation using measurable surface parameters. Real ambient noise recordings from the three regions have been used to analyze the ambient noise variations in the three regions. Descriptive statistics based on box plot and pdf analysis has been used to present the variations in the ambient noise spectral characteristics for the three regions.

Breaking waves generated by wind and wave interaction are reported to be the dominant mechanism for the generation of ambient noise, although some researchers do admit that this mechanism is not fully understood (Harland and Richards, 2006). The analysis of in-situ SSP and real ambient noise data show a wide variation in SSP and ambient noise statistics of the three regions. The study shows distinct ambient noise characteristics in the tropical region with relatively high variation of standard deviation and kurtosis corresponding to higher SST, wind speed, and wave height anomaly. The ambient noise generation process, right from the SSP, if modeled accurately can facilitate precise and early estimation of the ambient noise and subsequent enhancement of sonar performance (Etter, 2009; Asolkar et al., 2016). Regional data pertaining to the each of the sea surface parameters recorded at each of the three buoys has been analyzed for distribution fitting to understand the characteristic differences in the three regions. The wind speed and the wave height follows a Weibull distribution with corresponding scale and shape parameters and the SST follows a normal distribution with corresponding mean and standard deviation.

2. Measurement locations and methodology

Various studies have presented the impact of different SSP on ambient noise (Wenz, 1971; Urick, 1983). In this study, we have focused on wind speed, wave height, and SST to study the correlation of SSP and ambient noise. Knudsen and Urick have presented the impact of wind speed and wave height on the ambient noise level in the shallow waters of the Pacific with the majority of observations in the temperate region (Wenz, 1971; Urick, 1983). Local, regional and geostrophic SSP have a great impact on ambient noise and hence shows variations in ambient noise characteristics. In this work, we have used open source sea surface buoy data from three sites in each region for the analysis of the distribution of sea surface environment. Underwater ambient noise data from three regions has been used for the analysis of regional ambient noise characteristics. The SSP buoys are chosen such that it represents diverse characteristics of the regional environment and represents minimum distance between the acoustic measurement site and the SSP measurement location. The measurement sites are shown in Fig. 1 where, the *pentagon* represents SSP data location whereas *star* represents acoustic data location.

Hourly data of sea surface parameters, like wind speed, wave height, and SST from each region have been obtained from ocean observatories of the corresponding regions. The SSP data of three buoys from each region for the duration 2010–2013 has been considered for the analysis. The buoys from tropical and temperate region provide hourly data for a whole year whereas polar buoys provide data for three months of a year. The location, data length and inference of the data from each buoy has been presented in Table 1. The missing data samples and recordings with poor quality flags have been interpolated at the time of analysis (INCOISE, 2017; NOAA, 2017; EOL, 2017).

Acoustic data used for ambient noise analysis in the tropical region was collected in the Arabian Sea off the coast of Goa. Four ITC 8264 omnidirectional hydrophones have been placed horizontally along the east-west direction with 100 m spacing between the sensors. The