Chapter

Underwater Ambient Noise

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Abstract

Underwater ambient noise is primarily a background noise which is a function of time, location, and depth. Background baseline of the noise in ocean is represented by ambient noise generated from the ocean surface due to wind and rain. This understanding pertained to ambient noise under various conditions will help in improving the signal-to-noise ratio (SNR) of marine instruments. It is of prime importance to detect the signals such as sound of a submarine or echo from a target surpassing this ambient noise. Ambient noise excludes all forms of self noise, such as the noise of current flow around the measurement hydrophone and its supporting structure. It should also exclude all forms of electrical noise. It is also defined as the residual noise that remains after all easily identifiable sound sources are eliminated. In the absence of sound from ships and marine life, underwater ambient noise levels (NL) are dependent mainly on wind speeds at frequencies between 100 Hz and 25 KHz.

Keywords: ambient noise, underwater, shallow water, wind noise, background noise

1. Introduction

Nature is wonderful to observe, study, or analyze its diversity. It had thrown challenges to man in the past, and still this study is ever exploring. For the past many years, acoustics and oceanographic study have been interrelated. Ocean is a pandemonium of different sounds. Underwater acoustics has become the natural interest to many researchers throughout the world for the simple reason that it is so complex to study and analyze. The sources of sound are breaking waves, marine life, various sources of nature, and rain. Shipping also becomes an important factor for the noise generation along with several other man-made sources like military sonar for the source of sound. These sounds exist throughout the year along with the sounds that are seasonal.

Underwater ambient noise is a constituent of background noise that depends on depth, time, and also w.r.t location. Self noise does not belong to the category of ambient noise [1]. Ambient noise is the residual noise that would exist even after recognizable sources of sound are removed. Ship traffic contributes to the major component of ambient noise, whereas the noise generated by a nearby ship is considered as sound signal and is not a part of ambient noise [2].

For valid measurements of ambient noise, all possible sources of self-noise must be eliminated or at least reduced to an insignificant contribution to the total noise level (NL). Self noise sources, such as cable strumming, splashes of waves against the hydrophone cable, and sometimes even crabs crawling on the hydrophone, must be absent.

2. Ambient noise: frequency dependency

The classification of primary sources of noise can be done by taking frequency as a parameter. For example, ambient noise because of distant ship traffic exists between 20 and 500 Hz. In the absence of noise due to ships that are nearer to the receiver, also noise can be identified, which is obviously due to distant ships. Noise is higher in high ship traffic locations. For example, in the southern hemisphere, where there exist fewer ships, naturally low-frequency ambient noise levels are recorded. With the increased ship traffic, the noise produced is also high in international waters [3].

Ambient noise generated due to spray and bubbles related to breaking waves fall in the range of 500–100,000 Hz [4, 5]. With the increase in wind speed, ambient noise also increases. After 100,000 Hz, thermal noise dominates. Thermal noise is the noise due to random motion of water molecules, which is sometimes considered as threshold [6].

Knudsen et al. [7] studied ambient noise in harbors and in coastal waters. This study reveals the fact that the noise level raises with the increase in speed of the wind and wave height. At a specified wind speed, noise level decreases along with the incremental values of frequency. It has been observed that in the frequency range of 500 Hz to 50 KHz, ambient noise is a function of wind speed. This encourages researchers to use this as a means to measure wind speed over the ocean.

Apart from the sources of ambient noise that have been listed out, several intermittent sources exist in the ocean, which include marine life, man-made, and natural processes. These intermittent sources are limited to particular regions of ocean.

3. Ambient noise due to intermittent sources

The influence of intermittent sources on ambient noise is significant, which includes various factors such as marine life, rain noise, shipping noise, etc.

3.1 Marine life

A distinct and innumerous variety of sounds are produced by marine life. Humpback whales, dolphins, and other marine mammals generate sounds of a broad range of frequencies, and these sounds can be treated as infrasonic or ultrasonic. Specific categories of fish and marine invertebrates are also sources of sound. For example, special species of fish includes toadfish and croaker, and some of the marine invertebrates are snapping shrimp. Information pertained to surroundings is obtained by marine animals using sound. This dependency on sound extends in communicating, navigating, and even feeding. For example, dolphin depends on sound to search food and smell enemies. This is done by transmitting sound pulses for short intervals, and then with the echo received, dolphins detect objects in sea. Most of the time, this kind of communication contributes to raise in ambient noise levels for a maximum value of 25 dB. In the case of whales, noise levels are up to 190 dB at 10–25 Hz frequencies [6].

Sound produced by snapping shrimp inhabiting in shallow waters contributes to background noise. In general, prevalence of this can be seen in semitropical and shallow tropical waters which contain seabed with rock and shell, as they provide the necessary concealment. Colonies of snapping shrimp produce sounds at frequencies of 2–15 KHz. Individually these have peak-to-peak source levels of 189 underwater dB at 1 m.

It is also possible that the sounds that are known to humans and pertained to underwater have the sources that include more than the species that have been identified.

3.2 Natural physical processes

Most of the physical processes produce higher levels of sounds with source levels up to 260 underwater dB at 1 m. Rain, undersea earthquakes, and underwater volcanoes generate intermittent sounds in the ocean. Heavy rain raises noise level by 35 underwater dB from few Hz to beyond 20 KHz.

3.3 Human activities

Human activity is one of the important sources of background noise. Sounds in underwater are used for many purposes like communication, navigation, and fishing, and the point of observation is that one act is source for the other activity. Several by-products can also be seen like noise generation by offshore activities such as oil drilling, manufacturing, and other industrial acoustic pollutions. Incidentally and evidently, all of these factors, more or less, have a human hand in it. So, it is very clear that human activities also contribute to ambient noise of the underwater acoustics.

3.4 Rain noise

Nicolaas Bom [8] studied the influence of rain on undersea noise level. Experiments were conducted in Italy at the lake of Sarzana near La Spezia. Data is analyzed between 300 Hz and 96 KHz. The observation and inference of this work reflected the effect of rain on noise, i.e., noise level increases w.r.t to increased rainfall rate. It was concluded that "it corresponded to higher frequency energy."

In 1986, Nystuen [9] reported that a light rain with total rainfall of <2.5mm per hour produced a spectral peak at 15 KHz (broadband wind sensitive). And, a heavy rain where a total rainfall was more than 7.5mm per hour produced a wideband noise ranging from 4 to 21 KHz. A similar type of study and data analysis was done by Deane [10] for a period of 1 year, and this work also revealed the effect of rain noise.

3.5 Shipping noise

Shipping noise can exhibit both spatial and temporal variability. The spatial variability is largely governed by the distribution of shipping routes in the oceans. Temporal variability can be due to the seasonal activities of fishing fleets. The noise generated by coastal shipping and by high-latitude shipping can contribute to the noise field in the deep sound channel in tropical and subtropical ocean areas. Specifically, coastal shipping noise is intruded into the deep sound channel through the process of downslope conversion. High-latitude shipping noise is generated through the latitudinal dependence of the depth of the sound channel axis.

3.6 Wind-generated noise

Noise due to wind is a major contributor of the total ambient noise. Wind-associated ambient noise was predicted and analyzed earlier by many researchers. Ambient noise depends on varying wind speeds over the frequency range of 500 Hz to 50 KHz. In this range of frequency, i.e., in KHz, hydrophone is used as an anemometer [1]. Wind speed is considered as the major constituent of ambient noise in the absence of ships and tumid marine life.

Wind noise can be treated as a typical case of random noise. Wind noise in the frequency range of 500 Hz to 20 KHz is called as Knudsen noise, because Knudsen discovered that it correlated very well with wind speed [7].

4. Ambient noise level

Wenz curves are very helpful in the prediction of the level of ambient noise under given constraints. Wenz curves as shown in **Figure 1** represent the average ambient noise for different shipping traffic levels and wind speeds.

Ambient noise level variation w.r.t frequency can be well understood from Wenz curves, and this can be summarized as follows:

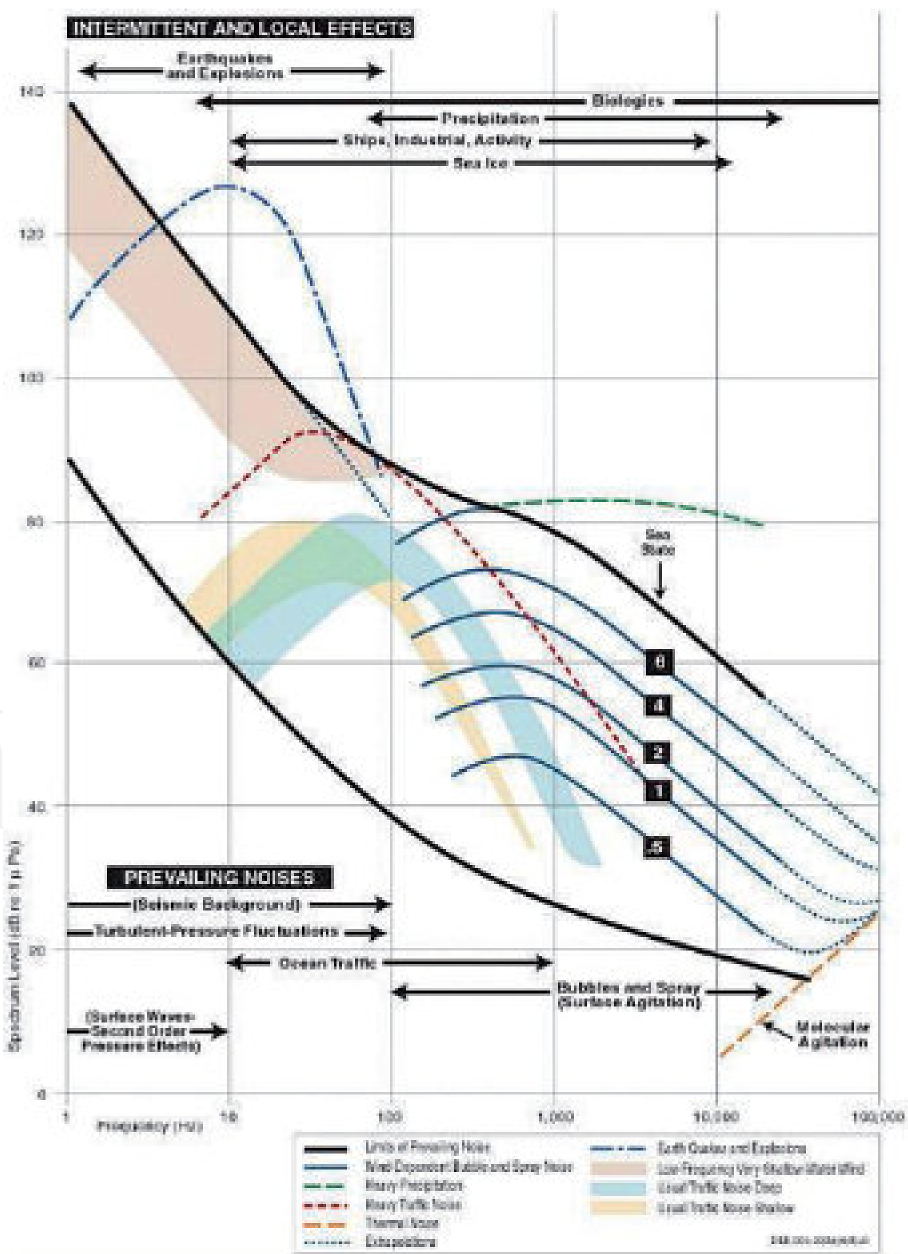

Figure 1.
Wenz curve [11].

- 10–100 Hz—In this band noise level depends mostly on shipping density and activities related to industries. In such cases noise levels are in the range of 60–90 dB with less-frequency dependence.

- 100–1000 Hz—Here shipping is the primary source of noise. Sea surface agitation is also a contributing factor to noise with this frequency range.

- 1–100 kHz—Sea surface agitiation is the dominant factor unless and otherwise marine mammals or rain is present.

- >100 kHz—Noise in this range is dominated by electronic and thermal noise.

The main inference can be drawn out of Wenz curves as "noise level (NL) decreases as depth increases and also w.r.t change in frequency, because most noise sources are relatively closer to the surface."

5. Ambient noise in shallow water

Shallow water ambient noise is highly random due to the waveguide nature of the environment and bottom reflection [12]. There are two definitions of shallow water: hypsometric and acoustic. The hypsometric definition is based on the fact that most continents have continental shelves bordered by the 200 m bathymetric contour, beyond which the bottom generally falls off rapidly into deep water. Therefore, shallow water is often taken to mean continental shelf waters shallower than 200 m. Using this definition, shallow water represents about 7.5 percent of the total ocean area.

Acoustically, shallow water conditions exist whenever the propagation is characterized by numerous encounters with both the sea surface and the seafloor. By this definition, some hypsometrically shallow water areas are acoustically deep. Alternatively, the deep ocean may be considered shallow when low-frequency and long-range propagation conditions are achieved through repeated interactions with the sea surface and the seafloor.

Shallow water regions are distinguished from deep water regions by the relatively greater role played in shallow water by the reflecting and scattering boundaries. Also differences from one shallow water region to another are primarily driven by differences in the structure and composition of the seafloor. Apart from water depth, the seafloor is perhaps the most important part of the marine environment that distinguishes shallow water propagation from deep water propagation. The most common shallow water bottom sediments are sand, silt, and mud, with compressional sound speeds greater than that of the overlying water.

In shallow water, in the absence of local shipping and biological noise, wind noise dominates the noise of distant shipping over the entire frequency range [1]. The reason for this is that the deep favorable propagation paths traveled by distant shipping noise in deep water are absent in shallow water.

Shallow water is known for its variability. Waters close to shore and in busy harbors are dynamic locations, where rapid noise changes take place. Even though shallow water has the variability as a notable feature due to variable background of biological and shipping activities, at high frequencies and even at high wind speeds, this level is significantly constant from location to location at the same wind speed. Although noise field characterization is complex in shallow waters, it has to be carried out because of its greater applications in naval operations.

Ambient noise is more in shallow water as the noise is pinned between the seafloor and the surface of the ocean. In shallow water (depth of 5–200 m), acoustic systems like sonar, echo sounder, and sub-bottom profiler suffer a huge loss due to ambient noise [13]. Wind speed in shallow water may vary from 0.5 m/s to 300 m/s; hence it causes disturbance to surface water, and these disturbances thereby propagate towards the seabed. Due to these factors the SNR value reduces. This poses a greater challenge to developing a method or algorithm to improve the SNR value. Hence, to improve the effectiveness of underwater acoustic instruments, the measurement and characterization of ambient noise is more significant.

6. Characterization and denoising of ambient noise

Characterization of ambient noise had become the epicenter during World War II. The need to develop acoustic sensor and systems had become of prime importance for processing different sound signatures of submarines [1]. This emphasized the need of noise characterization, and with this interest, many engineers and researchers started working with sensors and sonar for signal reception and processing.

After characterization of ambient noise, data analysis comes, which is essential for research and pragmatic approach. It serves two objectives: determining parameters that are needed for constructing necessary model and thereafter authenticating the constructed model.

Irrespective of physical measurements or quantitative modeling, data has one or more issues to deal with: (1) shorter total data span, (2) nonstationary data, and (3) data representing nonlinear processes. Here the first two issues are interrelated, for section of data shorter than the longest timescale of a stationary process may appear to be nonstationary. There are limited options available to analyze this kind of data (http://rcada.ncu.edu.tw/).

The recovery of the signal buried in ambient noise is of importance for the target's signal detection, recognition, and classification at low signal-to-noise ratio (Tieshuang et al. [14]).

7. Conclusion

In this chapter we have done a detailed study about underwater ambient noise, various sources that produce the noise, and shallow water ambient noise. In science and engineering, noise is defined as an unwanted energy. Noise is relentless that blots out or reduces the intensity of a signal. Noise can be a disturbance that may be internally generated because of the process itself or due to some irresolvable issues or may be due to intermittent and local instability. This can be produced by various recording systems and different types of sensors. It is important to analyze the data differences that would exist between actual data and the noise so that attempts can be done to remove this noise.

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