Research Note - I

Review to 3-D mapping of Low frequency ambient shipping noise

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Introduction

The history of underwater sound modeling takes us back to the 19th century where in 1826, a Swiss physicist Jean-Daniel Colladen and a french mathematician Charles-Francois Storm using a bell apparatus measured the speed of sound in waters of the lakes at Geneva, Switzerland using a bell apparatus leading to value of 1435 m/s at 8°C [1], that now comes within 2% of currently accepted values. Although underwater sound propagation strengthened its roots in the research sector with the outbreak of World War-I unleashing a flurry of activity in underwater acoustics. Following up with the event came an instance where the greatest of all ships believed of that time THE TITANIC sinking in 1912, English mathematician and meteorologist L.F. Richardson filed an application at the British Patent Office for echo ranging with airborne sound; and a month thereafter he returned with yet another proposal for an underwater analog.

It was with the advent of these instances that opened a new arena for minds from all across the world especially for use in unrestricted submarine warfare. The military till now had found its way to underwater sound experiments. One of the instances which reflects this was when in 1916, under the British Board of Invention and Research, Canadian and British physicists formed the Anti Submarine Division (ASD) of the British Naval Staff. Working under strict secrecy, they affixed the codename “asdic” to refer to their aquatic sound experimentations and succeeded in using piezoelectric crystals to produce the world’s first underwater sound detection apparatus in mid-1917; [2] Shortly after the first world war Germans published their first extensive research paper where they theoretically described the bending of sound rays produced by slight temperature and salinity gradients in the sea and underscoring their importance in determining sound ranges. It was however after nearly six decades that their work was recognised bringing a revolution in its sector. And thereafter sound technologies like SONARS were implemented in commercial ships and bigger vessels.

It was then, with the increase in number of ships and bigger vessels over oceanic waters that drew the attention of researchers towards high levels of sound radiated underwater and how it affected the marine fauna in that region. Not only that but also it affects a wide range of receivers :crew, passengers inside the ship and inhabitants of the coastal areas. Assessment of underwater noise was increasingly required by regulators of development projects in marine and freshwater habitats, and noise pollution being a constraining factor in the consenting process. Noise levels arising from the proposed activity like of SONARS are modeled and the potential impact on species (mammals) of interest within the affected area is then evaluated.

Now it's culminated that with the advancements of complexity in technology used in SONARS, it has developed our interests in knowing underwater acoustic propagation in greater detail. Although previously Ray theory and Parabolic equations were used for mathematical modeling of 2D sound propagation, its practical implementation limits its applicability in 3D analysis. Most commonly used term for this way of modeling is a (N X 2D) technique.Where models were sequentially executed for N adjacent range-dependent 2D radials. Paul_C_Etter [3]

The aim of this work is to cover all the different models that have been developed so far, which enable us to develop a complete three dimensional version of Underwater Low Frequency Shipping Noise propagation in conjunction with other recording platforms such as hydrophones. The research work that has been done using both the techniques are discussed below.

Three-dimensional propagation modeling in conjunction with seamounts

The very first method that has been implemented is through simulating acoustic interactions with seamounts (Medwin et al 1984) [4] and with mesoscale oceanographic features (Kuperman et al., 1987; Tsuchiya et al., 199) [5,6], coupling it with the appropriate color graphic displays and 3D modeling promises to be a powerful analytical and predictive tool. It is a hybrid solution formed by combining a range-independent model to calculate acoustic propagation to and from the seamount, along with the 3D physical models of the frequency-dependent wave interaction at the seamount.A ray trace illustrating interaction with a seamount is presented in Figure-1.

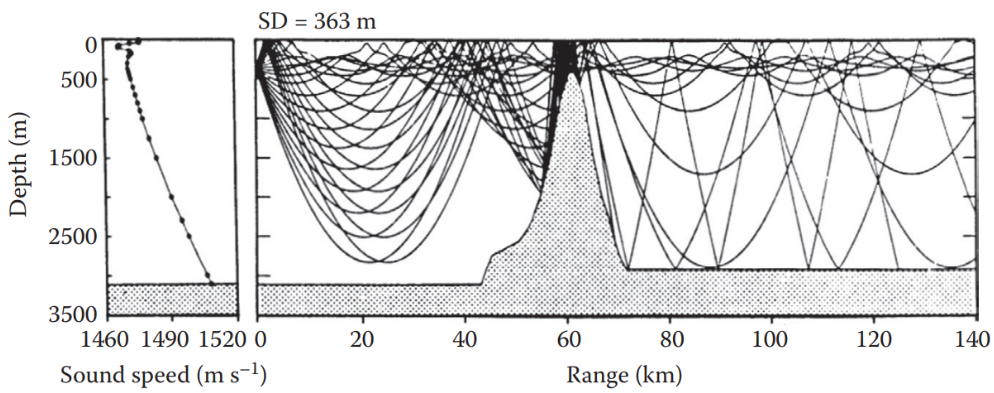

Figure -1 Three-dimensional predicted model to look like

Comparing it with the experimental data obtained from the Dickens Seamount in the northeastern Pacific Ocean (Chapman and Ebbeson, 1983; Ebbeson and Turner, 1983) verified the model accuracy in the frequency range 50–500 Hz.

Applications :

1. Here we measure, depending on the roughness of the sea surface, diffraction over the crest of the seamount, because it is a stronger contributor in analyzing the sound field. The diffracted signal always arrives before the multiply reflected sound.

2. Using a more realistic 3D model produces lesser diffraction and multiple reflection signals as compared to a more generalized 2D model. Which increases accuracy and transparency in the user interface. As an extra dimension is introduced here, it increases the arena of our consideration in which sound is propagating.

Underwater low frequency sound modeling using RANDI model

This noise model is designed to predict the response of low- to mid-frequency sonar receivers to the ocean acoustic noise field in locations with highly variable surrounding bathymetry and range-dependent sound speed structure. The RANDI II model is an ambient noise model that predicts noise levels and directionalities for user-specified environmental and shipping conditions using adiabatic mode theory to propagate energy from individual ships to a receiver array. Yet it has to face certain limitationsThe RANDI 3.1 model computes the shipping noise complex pressure (Kuperman and Ingenito 1980).[7]

The densities contain the expected number of ships within each grid for a month, season, or year. Five types of ships are identified according to size: merchant ships, tankers, large tankers, super tankers, and fishing vessels. The fishing vessel densities are given in the HITS 3.0 database, and they are averaged annually and for the winter and summer seasons.The source level of each ship here depends upon the length and speed of the ship.[8]

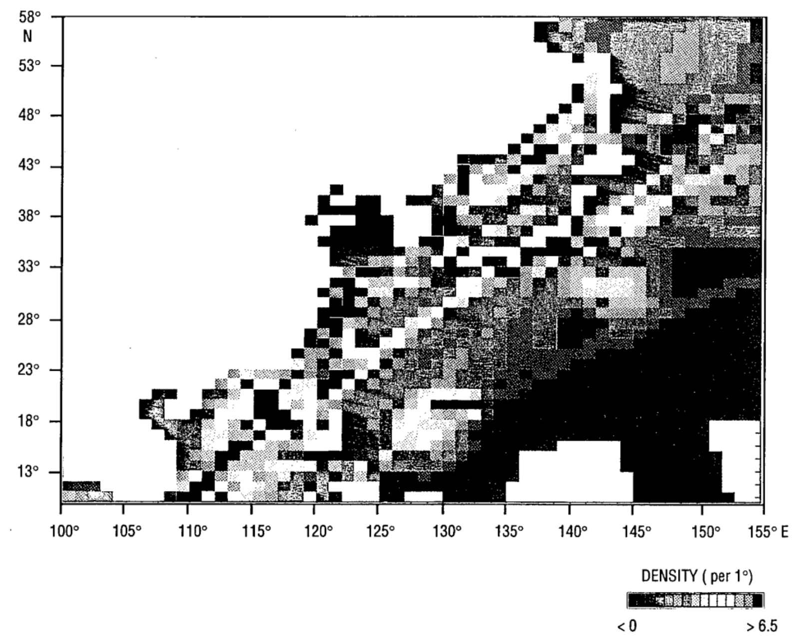

Figure 2. shipping densities are randomly taken in an oceanic region. All five classes of vessels are included

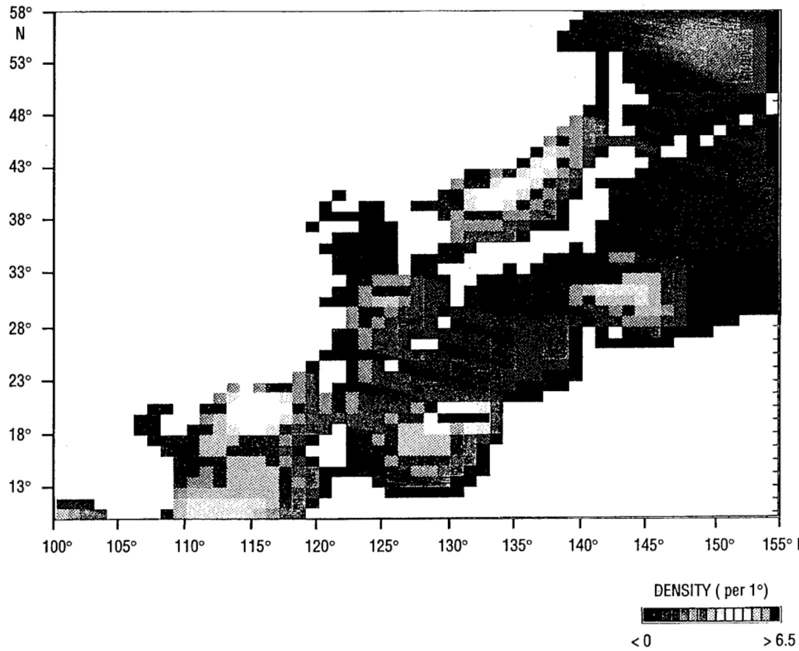

Figure 3. fishing vessel densities in a randomly selected oceanic region

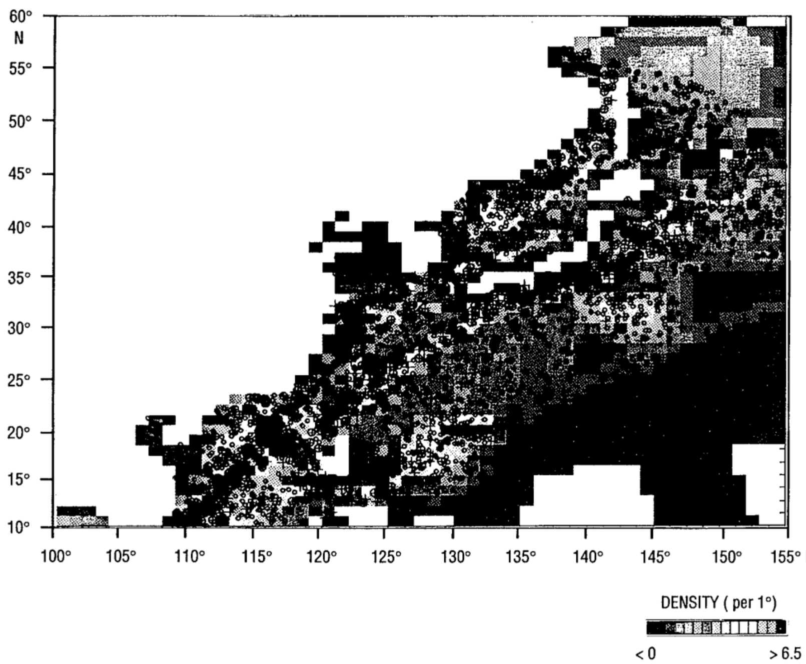

Figure 4. Discrete ships in a randomly selected region calculated with a Poisson distribution

Advantages

- It allows the user to input the BLUG parameters as they are extracted. The values are converted to the necessary bottom inputs, such as sediment and basement sound speed, density, and attenuation.
- It was the first advancing model in underwater acoustic to use solely based on bathymetry and range dependent sound speed. One of its kind to study just these two parameters.

Predicting underwater noise from cavitating propellers

The radiated noise from cavitating propellers covers a wide range of frequencies, with both tonal and broadband components. Tonal, or harmonic, components are associated with the blade passage frequencies, while broadband noise, as the name suggests, covers a wide and continuous frequency range. It is inclusive of the two major projects : The SONIC Project (Suppression of Underwater Noise Induced by Cavitation) and CETENA METHODOLOGY The identification of the sources here is based upon evidence that the pressure field of a propeller can be well simulated as the superposition of monopole and/or dipole pressure fields. [9]

It uses the following two test cases :

- VIRTUE Container Vessel, in model scale
- Research Vessel of the University of Newcastle, the PRINCESS ROYAL, in full scale

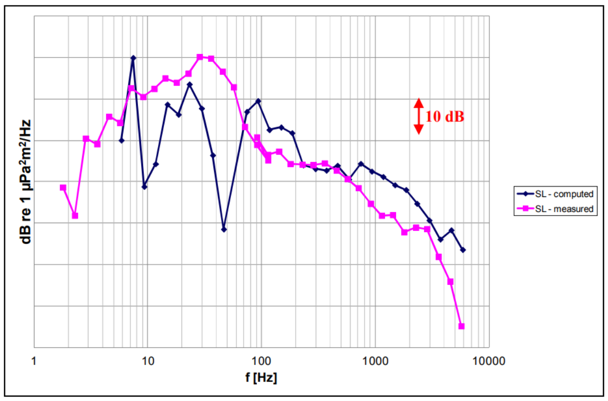

Figure 5. RESULTS – VIRTUE CONTAINER VESSEL

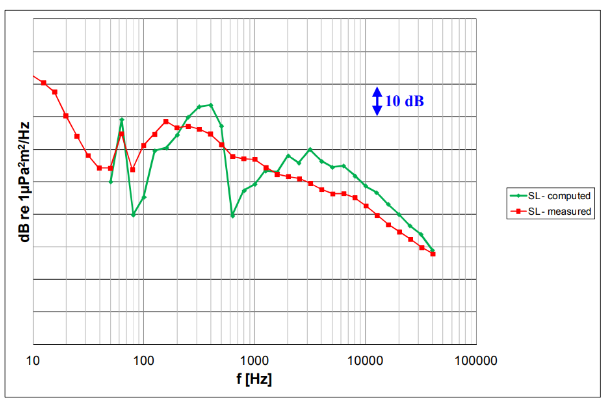

Figure 6. – SOURCE LEVEL – PRINCESS ROYAL

Advantages

- Developing tools to investigate and mitigate the effects of underwater noise generated by shipping, both in terms of the footprint of an individual ship and of the spatial distribution of sound from a large number of ships contributing to the sound.
- It is observed that cavitating propellers are a relevant source of acoustic emissions. In the frame of a general effort to reduce shipping noise, understanding and predicting the acoustic behavior of cavitating propellers has therefore clearly a high priority. So, it provides a more feasible and practical approach. [9]

Modeling using shipping density, source level and transmission losses

Another method used for the shipping noise modeling was using the shipping density, source level of the ships and transmission losses (Urick, 1983)[10]. A number of models exist for addressing underwater ambient noise (Etter, 2012)[11]. However, there has been a lack of simplistic analytical modeling tools developed for use by managers and for the assessment of environmental status (Erbe et al., 2012)[12].

The model is based on measurements obtained from vessel source spectra, automatic identification system (AIS) data, hydro-acoustic, geo-acoustic information, and environmental data such as bathymetry, sediment types, wind force and precipitation intensity. The model consisted of three modules. First being determining the source sound pressure levels of the vessels from the AIS data at each spatial location. The second module computes the sound transmission losses from each vessel source, taking hydro-acoustical and geo-acoustical factors into account. The data are then stored in a spatial data grid composed of 100 × 100 m squared cells. The third module is adding the noise contributions from the environmental factors (wind and precipitation intensity) to the sound pressure values acquired in each data cell (Erbe et al., 2012)[12].

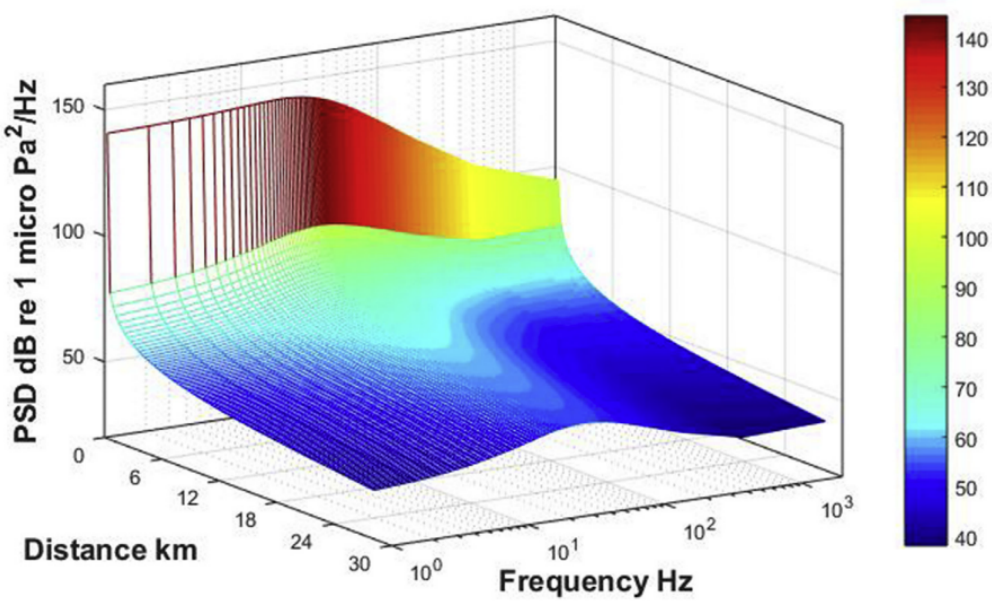

Figure . 7 : giving you a 3D variation plot of pressure in conjunction of distance (depth) underwater with respect to time

Modeling using Bathymetry, temperature, shipping noise and transmission losses

Taking into consideration the further advancements made by this model was it began with the application of shipping source spectra models available (i.e. Kraken 1992, Ross, 2005; Wales and Heitmeyer, 2002, Wittekind, 2014)[13,14,15,16] The Wittekind noise source model **separates the ship noise into a combination of three portions, which are due to low and high frequency cavitation as well as machinery noise**. These noise sources are related to the vessel specifications, such as displacement, hull shape and machinery characteristics.

Taking the AIS data available at marine traffic based on the different parameters like bathymetry, temperature, salinity and sediment adsorption coefficients. Finally taking the input parameters together into a PyRAM model in python for the calculation of overall transmission losses during sound propagation from bigger vessels and ships over the Indian Ocean Region at a more precise spectra. In a way here we are using a culmination of beginning with the 2D, 2½ D and then moving to the 3D mapping of noise transmission.[16]

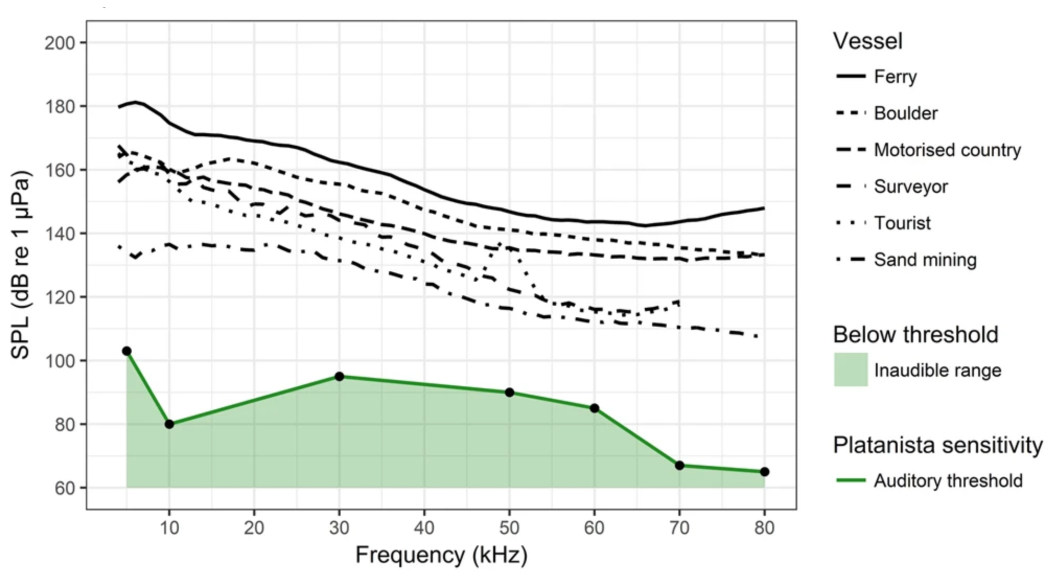

Figure 8. Depicts cumulative Noise Map for Pressure v/s Frequency parameters

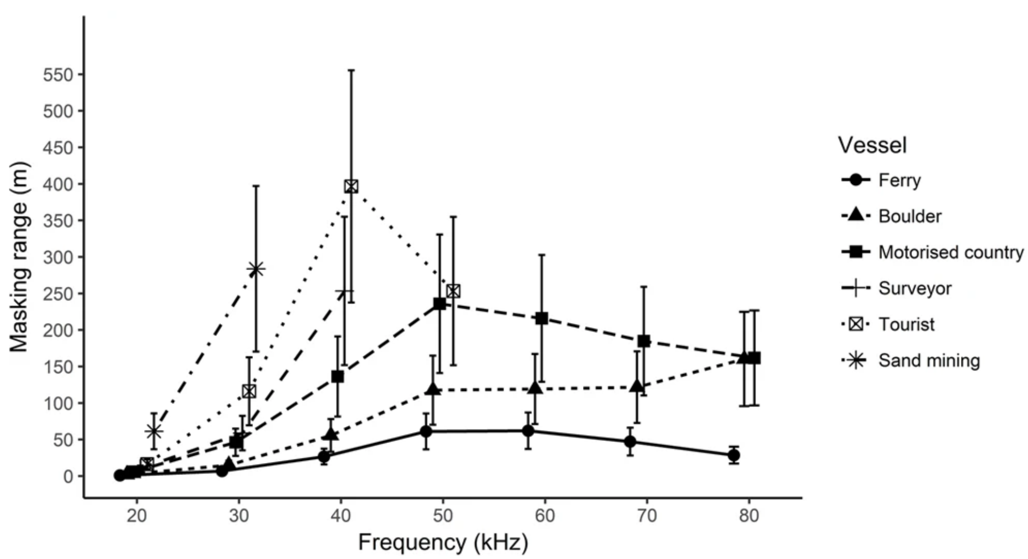

Figure 9. Pictorial representation of bathymetry analysis for different transmission and receiver points

Advantages

1. Moving with the 3D mapping, here an attempt is made to develop a complete software package which works not only for one time use but can be reset with the new dataset and be reused.
2. A three dimensional analysis of sound propagation provides higher precision and accuracy in calculations when considered reflection, refraction and transmission losses.
3. Opens up new dialects in the underwater sound research domain giving it a boost.

Further attempts to model Underwater Sound Propagation

The 3D Hamiltonian ray-tracing model, HARPO, has been used in tomographic studies of the ocean (Newhall et al., 1990; Jones et al., 1991)[20,21]. Both HARPO (Lynch et al., 1994)[22] and the 3D coupled-mode model CMM3D (Chiu and Ehret, 1994)[23] have been interfaced with sound-speed fields generated by the Harvard open ocean model (HOOM). (Lee and Schultz 1995) described a stand-alone 3D ocean acoustic propagation model. In a related work, (Perkins et al. 1993)[24]modeled the ambient-noise field in 3D ocean environments.

Future aspects to research on three-dimensional modeling of sound propagation

1. A three dimensional mapping of underwater sound acoustics can be used for scientific studies such as **to study the phenomena of noise behavior underwater.** Studying and reducing the transmission losses by understanding the conditions that persist in that region. The temperature variations, bathymetry, salinity etc..contributes to the sound propagation in any region leading to noise pollution, low frequency ambient noise affecting mammals underwater. So, in order to be able to protect them for generations to come, 3D-modeling will prove itself to be a milestone. It will increase our reach in the areas where human lives cannot go as covering wider ranges and greater depths will be introduced with a new dimension compared to the previously used 2D-modeling. At the beginning this method remained uncertain and was known as 2 ½ D (earlier referred to as the '2 X N' model as here we considered the 'N' number of blocks and added them to cover the whole region) . Yet today 3D noise models can be published via the internet so that the public can easily understand the transmission losses and their effect of noise pollution and can get involved in the process taking the research further. It is for the **tracking of trends** and should not be used to evaluate noise levels in individual locations andr at specific times.

2. Considering the time when the 2D-modeling was in use, its uncertainty always remained about the **Multi-path propagation of sound underwater , small bandwidth were available, serious signal attenuation** over large distances and **time variations of the channel** can now be made easier with 3D-mapping into the picture. Although as the number of dimensions increases it also increases the complexity of calculations and other measuring factors which is another point to overcome before its full fledged application . **Salty water or fresh water, level of impurities, pressure, composition of water and its temperature,** a culmination of all these parameters can be demonstrated in **one plotting** and so their scope of relating one with the other increases . Also not only this type mapping will allow us to see the density in regions but also allows us to divide the oceanic waters into layers and then determine the ores of minerals through letting the sound penetrate into the deep water and then looking for the mapping for ores with better results.

3. Another thing which is to overcome in future for successful implementation of three dimensional acoustics is **monitoring the environment**, as pollution of the ocean waters has increased in both quantity and frequency of occurrence. Because our scope of

coverage area in the oceanic arena increases, there will also be an increase in environmental conditions playing an inevitable determining factor. Other future applications of 3D- sound modeling are in **monitoring the level of pollution, detecting nuclear, biological, or chemical leakage in all sorts of water environments – lakes, bays or rivers**. Underwater Acoustic Networks can also survey and **estimate the impact of global warming on oceans**.

4. **High pressure of air and water combined**, unpredictable events, and **unknown subsea areas**. Underwater acoustic networks have applications in exploring the unknown regions in the ocean which majorly comes under the **future applications of 3D - Shipping sound mapping propagating underwater**. As there are unexplored regions underwater where 2D- plotting gives uncertainty in outcomes. Also in identifying the best locations for future UAN to be developed, increasing probability of their successful implementation .

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