Computer modeling of acoustic modem in the Oman Sea with inhomogeneities

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Present study is the acoustic rays and the propagation losses with the condition of inhomogenities present are compared to those with the condition of inhomogenities absent (by applying the Butterworth filter) with similar boundary conditions, for frequencies of 10Hz, 100Hz, 1 kHz and 10 kHz. This study shows that in the presence of finer inhomogenities, the sound energy in the region is highly scattered. In another words, because the wave length in higher frequencies are the same rank as these inhomogenities, the energy is more scattered. In the southern region of the Oman Sea in summer season, results show that in all frequencies, the reliable acoustic path (RAP) reaches the surface to ranges of at approximately 2 km for tsunami warning or general information.

[Keywords: Reliable Acoustic Path; sound speed; inhomogenities; Oman Sea]

Introduction

Today the technology of modem acoustic is used operators on the shore to remotely monitor deep ocean phenomena. For example, the Deep-ocean Assessment and Reporting of Tsunamis (DART) system aids the National Oceanic and Atmospheric Administration’s (NOAA) ability to remotely monitor pressure events near the ocean bottom uniquely associated with a passing tsunami wave. Ocean is a dynamic and continuously changing environment with many phenomena that have specific characteristics. Currents, internal waves, small scale eddies, horizontal stratification and other phenomena in the horizontal and vertical lead to sound speed variations. Sound velocity in the ocean is a function of temperature, salinity and pressure (or depth).

This sound speed is an increasing function of these variables. For example such equation which was presented by Wilson in 1960 is one that is as follow:

\[ C=1449.2+4.62T-0.0546T^2+0.0003T^3+(1.39-0.012T)(S-35)+0.017D \] (1)

This formula has a precision lower than 1m/s for the temperature and salinity ranges which are prevailing in the oceans. For using formula the temperature must be finite between 0 and 35 degree and the salinity between 0 and 45 PPT and the depth between 0 and 1000 m. An acoustic modem and sensor apparatus is anchored at the bottom of the ocean.

Ray acoustic traveling through the deep ocean can be received through various propagation paths (such as direct path, bottom bounce, surface ducts, etc.) depending on the environment, source/receiver depth and source of frequency. While the accumulation of the different arrival paths can cause the received signal to destroyed, “often one path will be dominant, and the transmission loss was minimum compared to other possible paths”1. One such dominant path is Reliable Acoustic Path (RAP). Some possible RAPs are shown in Figure 1.
The questions this study are, 1: Does the finer inhomogenities effect on RAP? 2: Which frequencies are effect on propagation sound?

**Materials and Methods**

A spatial survey was carried out in the Oman Sea during August 1995 by WOCE\(^1\) (Fig. 1) and vertical profiles of temperature and salinity (using Mini CTD system) were collected from all the stations. In this paper, acoustic modelling is discussed in the region of longitude 61°.19'30'' and latitude 22°.46'50'' in the south part the Oman Sea, as this area is marked with highly active meso-scale eddies. This area is shown in figure 2 as red point.

**Investigation of the sound propagation**

In this section, first by using the collected data of the salinity and temperature in the southern region of the Oman sea in summer season, the sound speed is calculated by Wilson formula, then by plotting the profile of the sound speed, In figure (3) was seen that there are the inhomogeneities from surface to depth 2500 meter These fine-structure fluctuations could be due to the quasi-geostrophic currents or the existence of fronts with internal waves with possible double diffusive layering\(^5\) and also careful look at to this profile reveals that at the depth of 1800 m we have a sound channel. It is noted that the sound channel is the place that sound speed is minimum value In order to calculate the field of acoustic pressure, in this work the code of Murty et al.\(^6\) in presence and absence of fine-structure vertical inhomogenities is used. In this calculation, in order to prevent the backscattered effects from the boundaries in the acoustic field, the characteristics of the boundaries at surface and bottom on all scenarios are considered as vacuum. From all those variables which change at the acoustic field, only the profile of the sound speed variations in vertical direction is considered. These scenarios done with frequencies 10 Hz, 100 Hz, 1000 Hz and 3000Hz then the results are compared with one another.

**Results and Discussion**

**Butterworth Filter Design on data**

As it is noted in the introduction the fine-structure inhomogeneities caused by the effects of meso-scale and small scale fluctuations. In order to calculate the fine structures and omitting these inhomogeneities on the profile of sound speed data in the region with longitude 61°.19'30'' and latitude of 22°.46'50'' in the Oman sea, the Butterworth 4th

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\(^1\) World Ocean Circulation Experiment
degree filter is used and a wide band is exerted (On the middle figure 4). If the data measured for sound speed is subtracted from the output of Butterworth filter the yielded results are the inhomogeneities of the environment. On the right figure 4 \( (\delta C^{(Z)}_z = \text{measured data} - \text{inhomogeneity}) \) is shown.

In order to investigation effect order of vertical scale of inhomogeneities, we analysis the quantity \( \log K_z \). This quantity is represented by the abscissa. Where \( K_z = \frac{2\pi}{\lambda_z} \) is the wave number and \( \lambda_z \) is the wavelength of the inhomogeneity, expressed in meters. In this region, the order of magnitude \( \delta C^{(Z)}_z \) was obtained 250-m. As a result, the dependence high frequency components of the vertical distribution of the sound velocity on the depth were obtained.

![Fig. 4](image)

**Fig.4** (a): The fine-structured fluctuations of the sound velocity about the average vertical distribution, (b): profile of the sound speed with the inhomogeneity (c): profile of the sound speed without inhomogeneity

**Sensitivity to fine-structure inhomogeneities variations**

The calculations of the sound field (with and without allowance for the fine-structure component) were performed for a modem acoustic at frequencies of 10Hz, 100Hz, 1 kHz and 10 kHz at depths of 1000 m, 1700m and 3000. In all condition, the sea bottom and sea surface were assumed to be vacuum. At first, the calculations were performed for a track with the smooth vertical sound velocity distribution (a plane-layered ocean with fine-structure inhomogeneities) and in the second case, without fine-structured inhomogeneities, modelled as described above. Figures 5 and 6 show contours of propagation loss calculated by the acoustic model in both cases (without and with inhomogeneities) for frequencies of 10Hz, 100Hz, 1 kHz and 10 kHz at the modem depth of 1000 m, respectively. One can see that the introduction of the fine-structure component generates a sound field reradiated from the thin high-gradient inter layers of the sound velocity and this field propagates into the shadow zones, where it considerably increases the field level relative to that calculated for the smooth profile. The brighter areas represent lower transmission loss and the RAP “region” is visible. In all condition, RAPs “region” were observed at approximately 2 km³. In the presence of inhomogeneities of the environment the acoustic energy at the channel is reduced drastically and the scattering of the sound by the vertical micro-structure inhomogeneities is produced in the environment, but in the absence of these inhomogeneities the scattering of sound energy is much less. When the modem is moved (the figures 7 to 10), the transmitted signal departs the deep sound channel boundaries and the effective range change. Almost in the absence of inhomogeneities in all frequency with source depth similar, these are observed that the transmission loss are the similar. As the frequency of the source gets higher, the wave length reaches to the rank of the vertical micro-structure scale, thus the scattering of the energy at the environment is gets higher and the blind environment spots at high frequency in the presence of these inhomogeneities vanishes. Thus the environment inhomogeneities in spite of sound energy losses caused the sound energy reaching more areas, making their existence an advantage. In figure 6, the sound channel with small thickness is observed; this sound channel in the absence of inhomogeneities would be vanished (figure 7). In the figures 5 to 10, these are observed that at low frequency (below of 10Hz) with lager wavelength of this source than the vertical micro-structure scale, the transmission loss is the same. In addition in these figures, the energy scattering in the inhomogeneities are not substantial. It is observed that the leakage of energy in the channel in the presence of inhomogeneities is higher than the absence of these inhomogeneities. The effect of the fine-structure inhomogeneities on the sound propagation also manifests itself in reverberation.
Fig. 5- Propagation loss contours in case of inhomogeneities absent (the modem is at the depth 1000 m and modem of frequencies are 10Hz, 100Hz, 1 kHz and 10 kHz, respectively).

Fig. 6- Propagation loss contours in case of inhomogeneities appearance (the modem is at the depth 1000 m and modem of frequencies are 10Hz, 100Hz, 1 kHz and 10 kHz, respectively).
Fig. 7- Propagation loss contours in case of inhomogeneities absent (the modem is at the depth 1700 m and modem of frequencies are 10Hz, 100Hz, 1 kHz and 10 kHz, respectively).

Fig. 8- Propagation loss contours in case of inhomogeneities appearance (the modem is at the depth 1700 m and modem of frequencies are 10Hz, 100Hz, 1 kHz and 10 kHz, respectively).
Acoustic transmission loss due to inhomogeneities at different receivers

To examine inhomogeneities effects on acoustic transmission loss, we calculate these transmission loss in both cases (with and without inhomogeneities) at depths of 1000m, 1700m and 3000m and for frequencies of 10, 100, 1000 and 10000Hz. Figures 8, 9 and 10 show the transmission loss at these depths versus range. As they were seen in figures 11 to 13, in the absence of inhomogeneities many shadow zones appear (the red line represent the presence of inhomogeneities and the blue line represent the absence of inhomogeneities). These figures demonstrate the importance of inhomogeneities and the
critical sensitivity of acoustical transmission loss (TL) to the inhomogeneities. As it is seen in these figures, in the absence of the inhomogeneities many blind regions appeared, for example, in figure 11 was seen in the absence of inhomogeneities in up frequency at the distance 23 km to 48 km the blind acoustic region is present. However, in the presence of inhomogeneities, the curve of the transmission loss has a lower number of blind acoustic regions because more energy scattering is observed.

Fig.11 - The transmission loss versus range for a 1000-m source and 1000-receiver with launch angles of ±20.3° with and without inhomogeneity. (The red represent the presence of inhomogenities and the blue represent the absence of inhomogenities).

Fig.12 - The transmission loss versus range for a 1700-m source and 1000-receiver with launch angles of ±20.3° with and without inhomogeneity. (The red represent the presence of inhomogenities and the blue represent the absence of inhomogenities).
Conclusion
The main findings of this study are: In the southern region of the Oman Sea in summer season, results show that the RAP reaches the surface to ranges of at approximately 2 km to tsunami warning or general information. Almost in the absence of inhomogeneities in all frequency with source depth similar, Contours of propagation loss are similar (figures 5, 7 and 9). The high-frequency (up 10Hz) sound propagation is affected by the fine-structured inhomogeneities. By investigation the transmission loss in this area, the results revealed that in the absence of inhomogeneities, the shadow zones are increased and in the presence of these inhomogeneities that cause the scattering of the sound energy in the environment, the energy can leak in sound channel. Thereby, results indicate that the inhomogeneities could be important in transmission.

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References
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