Channel as seen by an Argo Float: Study from Arabian Sea

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***Abstract*—The salinity-temperature profile data from one of the Argos float (ID: 2901374) in the Arabian Sea has been analyzed from June 2010 to March 2012 in this study. A major part of this study is to investigate the variable characteristics of underwater acoustic communication channel for long periods in the area where this float has gathered the data. We have many measured salinity, temperature, and depth profiles along the trajectory of the float. From this measured data, sound speed profiles at different locations, months, and seasons can be calculated using sound speed equations. The latitude span starts from 19.7° and goes to 24.3° whereas longitude span starts from 58.7° to goes to 64.8° approximately. A ray theory based modeling tool has been used to predict the parameters like multipath extent and delay spread which are useful for channel characterization of the acoustic wireless communication. In this way, use of actual and recent ocean data can be used in performance prediction of acoustic communication system.**

Keywords—Argos; Salinity-temperature profile data ; Arabian Sea

I. Introduction

Underwater acoustics has been a key research area for various applications since longtime. These applications include commercial and military sonar systems, wireless telemetry, remote control, speech and image transmission, environmental monitoring, oceanographic data gathering , marine archaeology, and search and rescue missions etc. [*1*].

As we know that acoustic waves require physical channel and the properties of the channel influence prorogation of these waves. The acoustic properties of the channel are strongly influenced by the oceanographic and environmental conditions. Some of the factors that affect the underwater acoustic channel include Sound speed profile in water column, ocean surface winds, internal tides and ambient noise etc. Out of all the oceanographic and environmental factors mentioned above, variation in sound speed profile is one of the major factors that govern the variation in the propagation of sound. Since speed of sound in water is a function of temperature, salinity and depth, and these quantities vary in space and time, the variability in underwater channel is introduced. Determination of this variability by experimentation is very expensive, time consuming and at times restricted [*2*]. This is why several approaches have been proposed to model the underwater acoustic communication channel(i.e. as given in [*3*], [*4*], [*5*], [*6*], [*7*], [*8*], [*9*], [*10*] and its references) . With the help of these models channel characterization required for acoustic system design, can be done to a certain degree of accuracy. The physics of the signal propagation also plays a key role when one wants to characterize the limitations (like maximum data rate that a channel can support, preferred modulation scheme etc.) of a given communication system. Therefore, it is important to model the propagation of the acoustic waves. With the help of these models, predictions about the acoustic system can be obtained.

An important pre-requisite for the reliable prediction of acoustic channel behavior is providing accurate input of the model with the actual temperature and salinity profiles. However, the data of these temperature and salinity profiles is generally not readily available for most of the oceans. Even when this data is available, it is irregular and sparse in space and time. This situation about availability of temperature and salinity data is improving due to Argo floats program [*11*]. The Argo network of autonomous profiling floats provides time-varying temperature and salinity fields of the upper ocean on global scale. Comprehensive current subsurface ocean data is available in the form of more than 10,000 temperature –salinity profiles per month from over 3200 floats of the Argo global array [*12*]. Many scientific and operational users are using Argo data for different purposes. It provides a quantitative description of the physical state of the upper ocean and the patterns of ocean climate variability, including heat and freshwater storage and transport [*11*].

II. Data and Methodology

A. General area and trajectory of the Argos Profile

The Argos float 2901374 was deployed in the Arabian Sea in June 2010 and it remained operational until sometime after March 2012. The longevity of the float was 1.88 years during which it obtained 199 profiles out of which 172 profiles were available. The float ended its life in Arabian Gulf near Iranian coast. In the present study, we have taken only 91 profiles out of the 172 available for this float because some had data quality issues or they were very similar to the ones included in the study.

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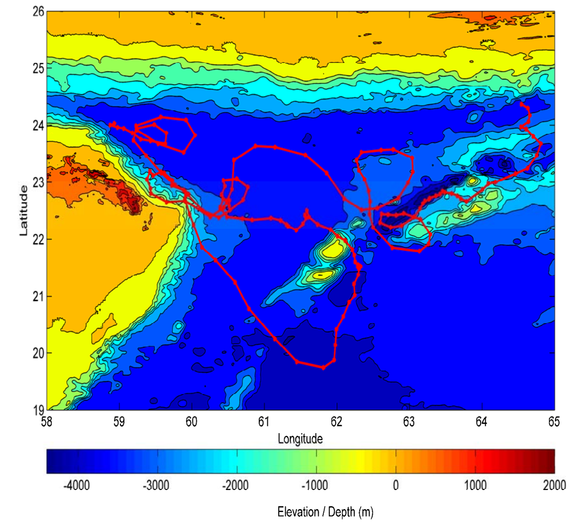


Figure 1 Bathymetry of the area and trajectory of the float

The following figure presents the bathymetry at the profiles reporting positions. The channel depth found from this figure comes out to be between 3000 m to 3500 m for most of the times. Only at 3-4 positions it encounterd relativly shallow depths along its trajectory .

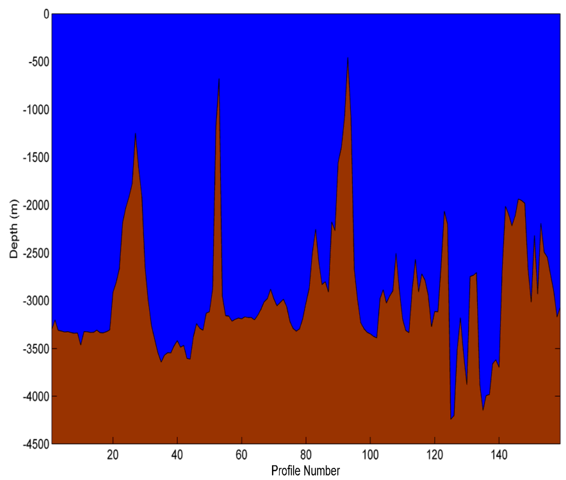


Figure 2 Bathymetry at float's reporting positions

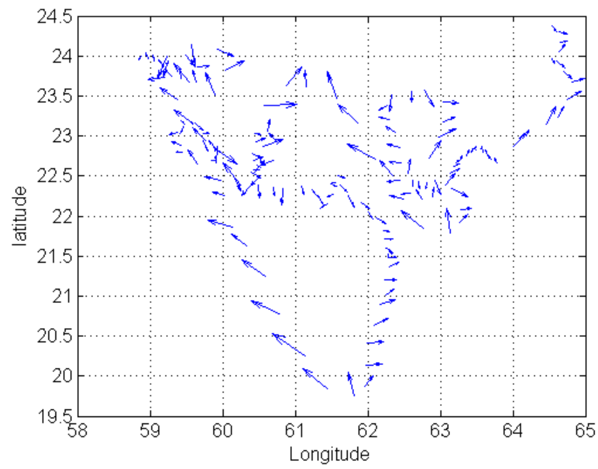


Figure 3 Course and distance traveled by the float (length of arrow represents the distance travelled)

The course and distance figure of the float show that the float undergoes cyclone and anti-cyclone movement during its drift along with the ocean.

B. Temprature and salinity data

The temperature and salinity data for the float are given in the figures below.

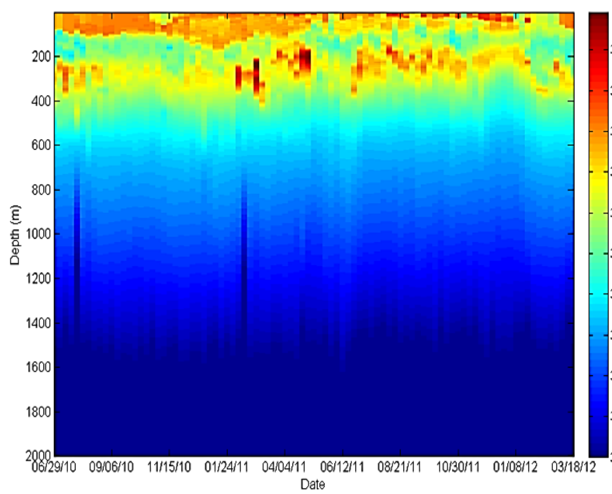


Figure 4 Salinity profiles (in PSU)

The salinity figures show the presences of subsurface waters with higher salinity at depths from 180 m to 250 m. this will induce density differential in the ocean and thus it is expected that there will be subsurface currents at that depth. This indicates that the moored modems at this depth might encounter Doppler shifts due to relative motion of the modems and medium.

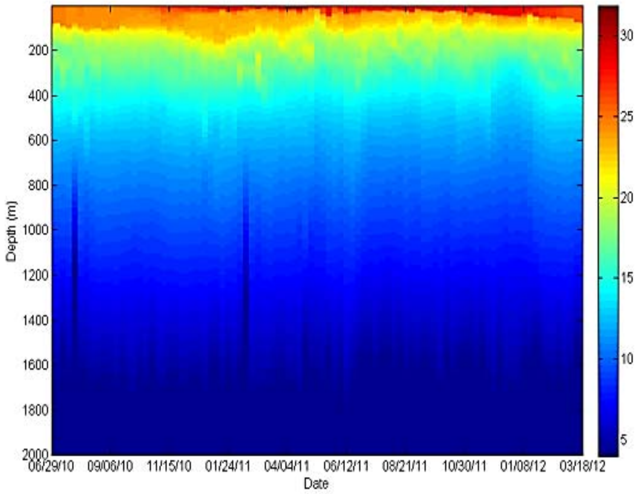


Figure 5 Temperature Profile (in degrees centigrade)

The sound speed profiles were calculated using salinity and temperature data using formula given in [*12*]. The applicability and simplicity of Mackenzie's formula leads us to use this simple compact form of speed of sound formula (a few coefficients as compared to about 44 coefficients of UNESCO's algorithm). Despite the fact that many new equations are available for calculation of speed of sound from salinity depth and temperature, we preferred this equation because of its simplicity and applicability to the present area. Some of the latest equations like given in [*13*] have used this simple equation as a reference for bench marking their results.

$$\boldsymbol{c(s,t,d) = 1448.96 + 4.591 \times t - 5.304 \times 10^{-2}t^2 + 2.374 \times 10^{-4}t^3 + 1.340(s-35) + 1.630 \times 10^{-2}d + 1.675 \times 10^{-7}d^2 - 1.025 \times 10^{-2}t(s-35) - 7.139 \times 10^{-13}t \times d^3}$$

Where t is temperature in degrees Celsius, s is salinity in parts per thousand and d represents depth in meters. The sound speed profiles thus obtained are given in the Figure 6

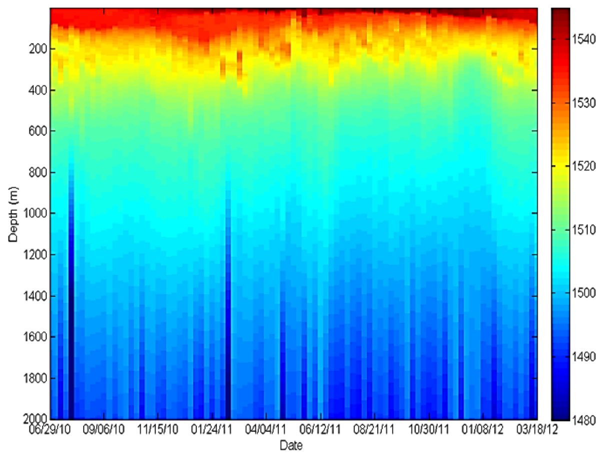


Figure 6 Sound speed profiles (m/s)

For the positions where the sea has greater depth than the profile depth the salinity and temperature have been interpolated by the last two samples to obtain the sound speed profile up to the full ocean depth at that position.

The float takes the measurements of ocean salinity and temperature as it ascends or descends slowly in the water column. Here we have assumed that one profile of the temperature and salinity belongs to a short duration of time in which the other parameters do not change significantly during the measurement.

C. Methodology

A common way of modeling the acoustic sound field is by means of ray theory. This is a high frequency approximation to the sound field. According to this approximation, sound is considered to be arriving over different ray paths. A rough rule for the validity of ray theory is that it applies when the spatial scale of changes in the medium is large compared to the wavelength. In the underwater acoustics, this translates to frequencies starting from below 5 kHz and upwards [*6*].

We have used the TV-APM code [*14*] for generating the time varying channel responses for each position. TV-APM code is built on Bellhop acoustic program that is a ray theory based modeling tool. It has been used to predict the parameters like multipath extent, transmission loss and delay spread which are useful for acoustic channel characterization [*15*]. The inputs of the code include sound speed profile, actual bathymetry of the area, seabed composition, wind speed and direction, transducer and receiver positions orientation and frequencies, relative speeds etc. The channel has been simulated with a single transmitter and receiver placed about 3000 m apart at 50 m depth. The simulation frequency is 6 kHz and sampling rate is taken to be 48 kHz.

III. RESULTS AND DISCUSSIONS

The results for the channel that are useful from the acoustic communication point of view have been obtained and discussed in this section. These include channel multipath response and delay spread (rms and mean). The results have been grouped together on monthly basis.

A. channel multipath response

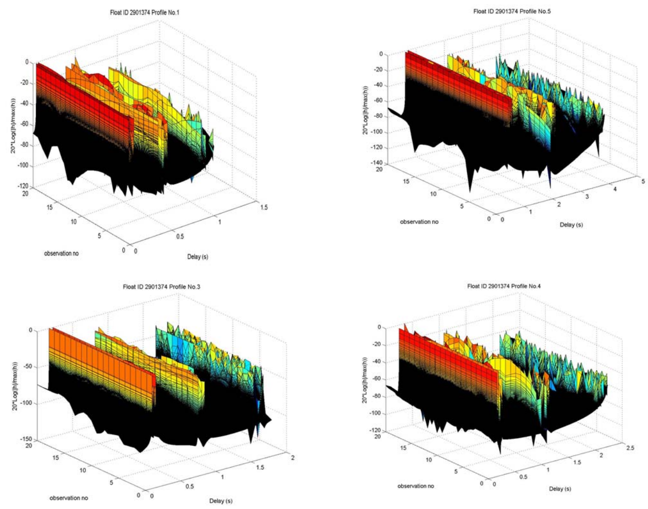
The channel multipath response for the data is presented next. These figures show the normalized value of $h(t, \tau)$ in log scale for better dynamic range presentation of the channel. The quantity

$$20*\log_{10} |h(t, \tau)/\max(h(t, \tau))|$$

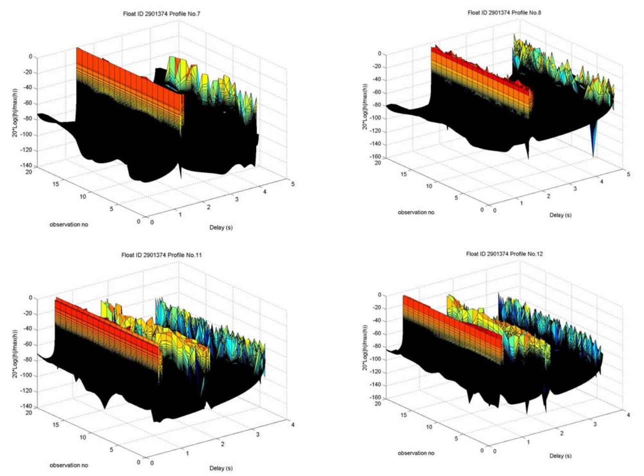
for the profiles has been plotted along z-axis. The x-axis represents the delay and the y-axis represents the observation number for the month/profile. The rough sea surface acts as a continuum of scatterers and the resulting channel has an impulse response in which arrivals are time varying. The profiles are normalized by the maximum of the group. The profiles are not individually normalized. This results in a channel response function that can be compared with each other for the same month and conditions.

The results of the simulation show a large diversity of propagation conditions in the channel due to the changing conditions. The importance of each type of propagation condition for system design depends on both its impact on communication performance and frequency of occurrence. The channel for most of the profiles is sparse with two or three distinct arrival groups. In very few cases, the channel is composed of only one arrival group. This is plausible because the float has obtained profiles from deep sea where sea surface and bottom provide additional propagation paths in addition to the direct path between the source and receiver modems. The delay time between distinct paths is related to the depth of the channel and the positions of the modems.

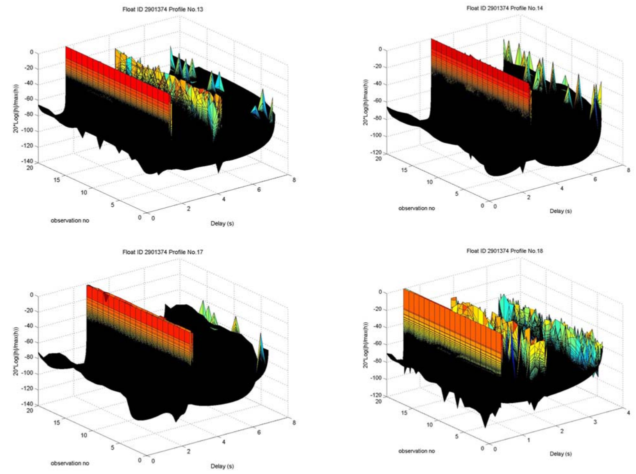
The channel multipath response for January is given as under.



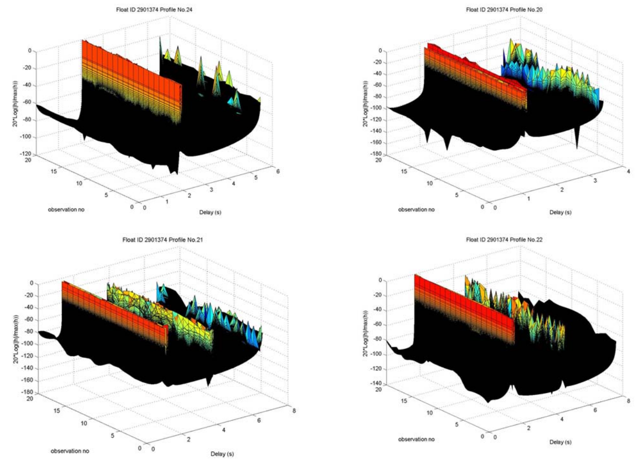
The channel multipath response for February is given as under.



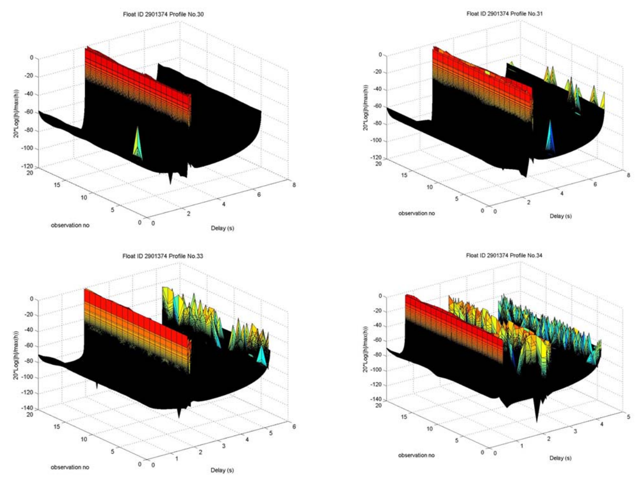
The channel multipath response of March is given as under.



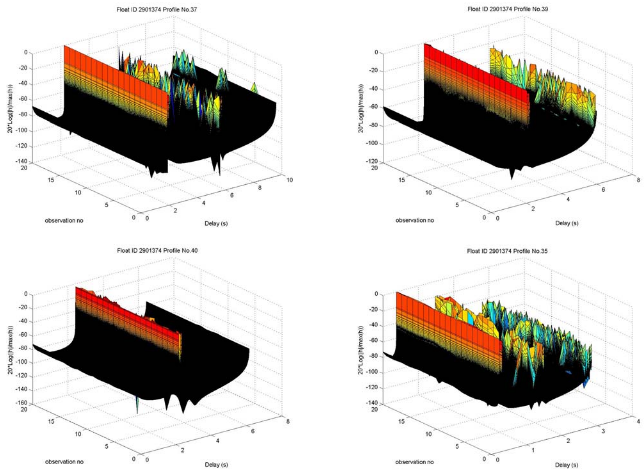
The channel multipath response for April is given as under.



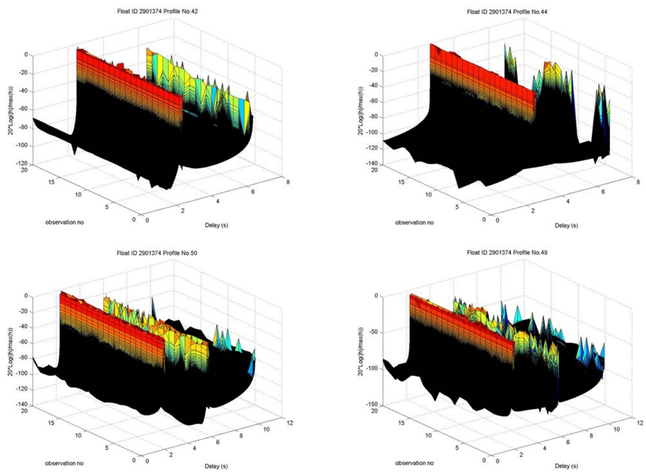
The channel multipath response of May is given as under.



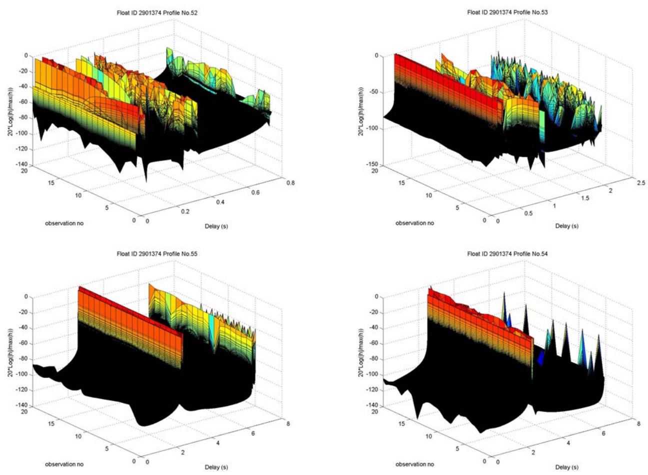
The channel multipath response of June is given as under.



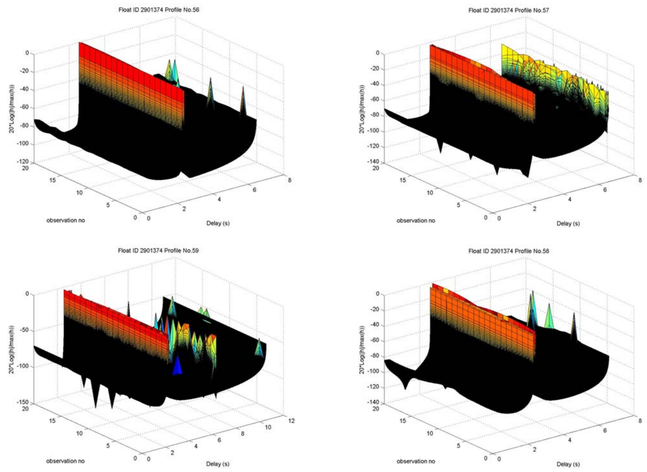
The channel multipath response for July is given as under.



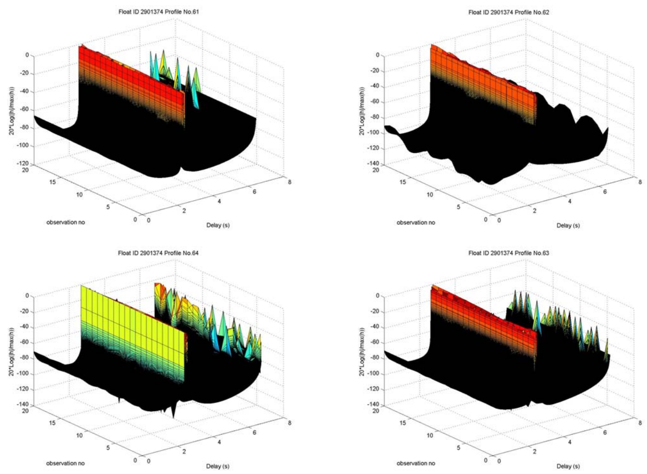
Channel multipath response for the data for august is given as under



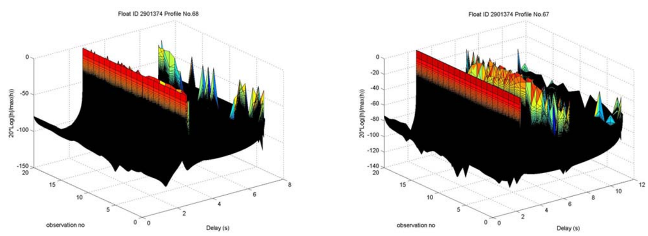
The channel multipath response for the data for September is given as under.

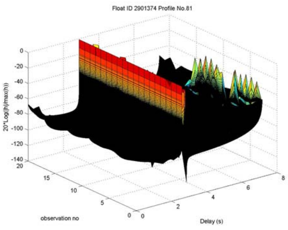


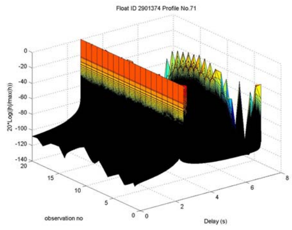
The channel multipath response for the data for October is given as under.



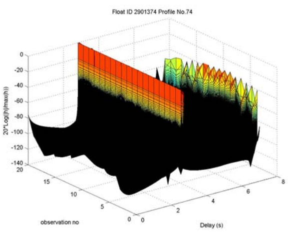
The channel multipath response for the data for November is given as under.

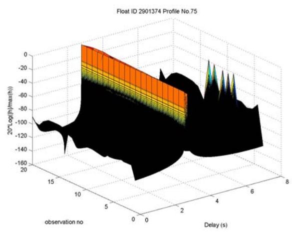


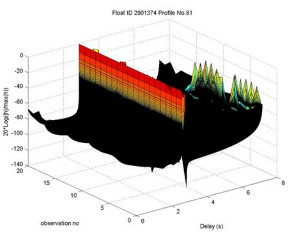


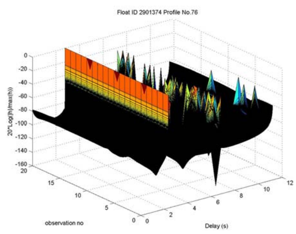


The channel multipath response for the data for December is given as under.









B. channel delay spread

Sometimes the average delay and rms channel delay is used to determine the channel characteristics. Definitions of average delay denoted as $\bar{\tau}$ and rms Delay denoted as σ_τ are given by the following equations

$$\bar{\tau} = \frac{\sum_k \tau_k p(\tau_k)}{\sum_k p(\tau_k)} \qquad \sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

Here $p(\tau_k)$ is the power delay profile associated with τ_k delay of the channel. $\overline{\tau^2}$ is defined as follows

$$\overline{\tau^2} = \frac{\sum_k {\tau^2}_k p(\tau_k)}{\sum_k p(\tau_k)}$$

The channel spread statistics have been gathered for each of the month. Since there are many channel response functions for each month so the average of the delay spread has been plotted along with its standard deviation as an error bar to show the mean value of the spread along with its variation around that mean. From the graph given in Figure 7, it is clear that for some of the months the standard deviation from the mean is large while some channel conditions show only small variations.

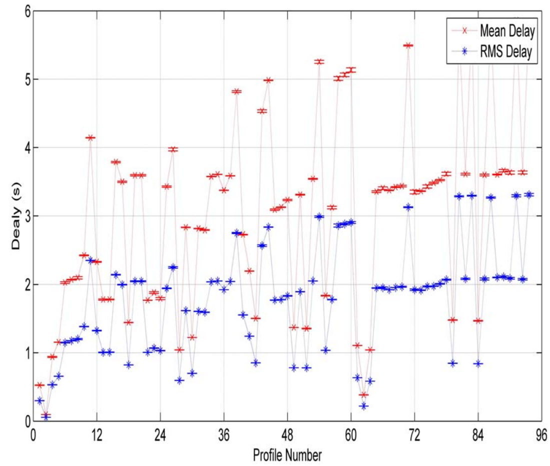


Figure 7 averaged channel delay spread for each profile

C. Channel transmission loss

As given in [*16*] for a source positions x_s , receiver position x_r and any frequency ω it is possible to define the channel transfer function $h(x_s\, x_r\, \omega)$ satisfying the following relation between transmitted signal $P(x_s, \omega)$ and received signal $P(x_r\, \omega)$:

$$P(x_r\ \omega) = h(x_s\, x_r\, \omega)\, P(x_s, \omega)$$

This represents the convolution operation in time domain. The transmission loss can also be computed from the transfer function in frequency domain as:

$$TL = -20 * Log_{10} |\, h(x_s\, x_r\, \omega)\, |$$

For calculation of transfer function for the given conditions many channel response function were obtained at various frequencies up to 48 kHz. The procedure adopted is similar to that given in [*17*] and can be referred to for the details. Since we have many channel multipath response functions for each profile so there are many values of the transmission loss. We take averaged value of the transmission loss at the frequency of the simulation. This is shown in Figure 8.

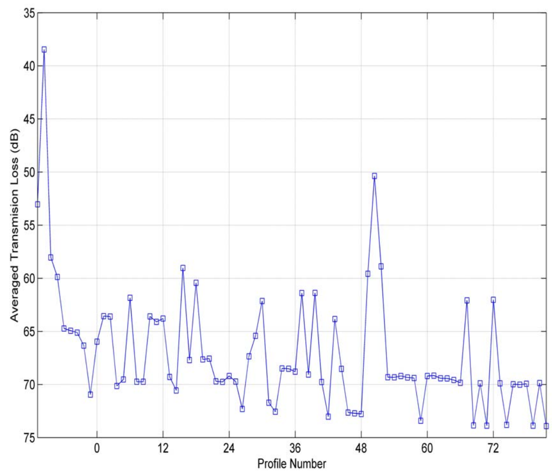


Figure 8 Average Transmission Loss of profiles

The transmission loss follows the trend of the mean and rms delay spread of the channel. This becomes clear if we compare the figure 7 and 8. For most of the profiles, the transmission loss figure remains between 60 to 70 dB at 3 km distance.

IV. CONCLUSIONS

Comprehensive current subsurface ocean data is available in the form of more than 10,000 temperature–salinity profiles per month from over 3200 floats of the Argo global array. In this paper, use of this actual and recent ocean data in prediction of some important characteristics of acoustic communication channel has been demonstrated for northwestern part of Arabian Sea. This is important in design phase of an underwater communication system where experimentation in field is not feasible and a number of alternative/competing designs have to be compared quantitatively.

ACKNOWLEDGMENT

The authors are thankful to the Chinese Scholarship Council (CSC) for awarding Scholarship to undertake this work. The Authors are also thankful to Prof. Qiao Gang, Dr. Feng Zhou and Mr. Rehan Khan for their precious guidelines in writing this paper.

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