CHAPTER I

INTRODUCTION

1.1 General Introduction.

Ph.D thesis under the same title was submitted for adjudication to the Cochin University of Science and Technology in 1991. The thesis is revised in the light of the observations made by the examiners and the present volume comprises the revised version being submitted in 1994. The whole text has been elaborately revised incorporating detailed discussions emanating out of more analyses carried out subsequently. The various suggestions made by the examiners have been kept in mind while preparing this revised thesis. The different questions raised by the examiners are discussed in detail at the respective portions of the ensuing chapters.

Of all forms of radiation known to man, sound, a form of mechanical energy, travels the best through the turbid, saline sea. Because of its relative ease of propagation, under water sound has been applied by man to a variety of purposes including the exploration of the sea.

Underwater sound, as a specialised branch of Science and Technology had been used in the two world wars. Although it has deep roots in the past, underwater sound, as a quantitative subject, may be said to be only a quarter of a century old. Its modern era began with the precise quantitative studies undertaken with great vigour during the days of World War-II. In subsequent years, there has been considerable progress in ocean acoustic research, particularly in the western countries, because of its
immense importance in such activities as mineral and oil exploration, marine surveys, fish finding, navigation, underwater communication, telemetry, etc. Much of the research now deals with the more complicated propagation picture that emerges when more realistic conditions are allowed. Attempts are directed to understand the effects of physical ocean processes and the boundaries on sound transmission. Numerical and analytical methods of modelling acoustic propagation are also receiving considerable attention. In the vast literature available on the subject, Indian contribution has been meager.

The coastal waters of Kerala present unique hydrographical features which would require detailed investigations on their sound propagation characteristics. The sea surrounding the peninsular India are subjected to spectacular variations in hydrography in response to the changing seasons. The climate in this region is controlled by the two monsoons. The southwest monsoon breaks over Kerala usually during the first week of June and continues till early September. During this period, the wind blows roughly from the south-west and cloudy conditions and frequent rains are experienced. During December and January, the general wind blow in from the north-easterly direction and there are occasional thunderstorms. During February the weather is fine and March, April and May are the months when summer conditions are experienced in this area. October and November form a transition period between the two monsoons. The coastal hydrography shows striking variations in response to the changing seasons.
Another remarkable phenomena encountered in these coastal waters in association with the south-west monsoon, is the occurrence of upwelling. Under its influence, the coastal waters experience sudden lowering of temperature, decrease in dissolved oxygen content and increase in nutrients. The upwelling is associated with increase in productivity which accounts for the high yield of fishery.

These hydrographic processes and variations influence the characteristic of the coastal waters as an acoustic propagation medium. The influence of hydrographic parameters on the propagation of sound in sea have been discussed by many authors (Matthews, 1934; Kuwahara, 1939). The velocity of sound in the sea increases with temperature, salinity and depth. In the open ocean temperature and pressure are the dominant parameters for the determination of sound velocity. In the coastal waters, however, salinity also may play a major part. Present thesis aims to bring out the nature of variability in the acoustical propagation characteristics of the coastal waters of Kerala and its relation to some important ocean processes.

1.2 THE STATE OF THE ART

1.2.1 Methods of Sound Velocity measurement

The velocity of sound in the sea is an oceanographic parameter that determines many of the peculiarities of sound transmission in the medium. It varies with depth, the seasons, geographic locations and with time at a fixed location.

The sound velocity is a function of oceanographic parameters such as temperature, salinity and pressure. A relationship between
sound velocity and these parameters can be established either theoretically or experimentally. Tables of sound velocity were prepared long ago using theoretical methods by Hack and Service (1924), Mathews (1934) and Kuwahara (1939), the last mentioned serving as standard table for nearly 20 years. By the experimental method, tables of sound velocity were prepared by different authors like Weissler and Del Grosso (1951), Del Grosso (1952) and Wilson (1960), the last receiving general acceptance till recent times. The empirical formula of Chen and Millero (1977) has now superseded Wilson's formula because the former is more accurate (UNESCO, 1983). Direct measurement of the velocity of sound is accomplished by a device called the velocimeter, first developed by Greenspan and Tschiegg (1957). It measures sound velocity directly in terms of the travel time of sound over a constant fixed path.

1.2.2 Sound Velocity profile

The velocity profile in deep water can be generally divided into three layers. Just below the sea surface is the surface layer in which the velocity of sound is susceptible to daily changes in heating, cooling and wind action. The surface layer may contain a mixed layer of isothermal water in which sound tends to be trapped or channeled and sound velocity increases as depth increases in the layer. Below the surface layer is the thermocline, where the temperature and hence sound velocity decrease rapidly. Underlying the thermocline and extending to the sea bottom is the deep isothermal layer having nearly constant temperature. In this layer sound velocity increases with depth due to the effect of pressure. Between the negative
velocity gradient of the thermocline and positive gradient of the deep isothermal layer there is a velocity minimum towards which sound tends to be bend or focused by refraction.

In the shallow waters of coastal regions and on the continental shelves, the velocity profile tends to be irregular and unpredictable and is greatly influenced by surface heating and cooling, changes in salinity and water currents. The shallow water profile is complicated by the effect of salinity variations caused by nearby sources of fresh water and contains numerous layers of different sound velocity gradients which have little temporal or spatial stability.

1.2.3 Wave theory and Ray theory

The propagation of sound in an elastic medium can be described mathematically by solutions of the wave equation using the appropriate boundary and medium conditions for a particular problem. The wave equation is a partial differential equation relating the acoustic pressure $P$ to the co-ordinates $x,y,z$ and the time $t$, and may be written as

$$\frac{\partial^2 P}{\partial t^2} = C^2 \left( \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2} \right)$$

where $C$ is a quantity that has the general significance of sound velocity and may vary with the co-ordinates. There are two theoretical approaches to solve the wave equation. One is called the ray theory, and the body of results and conclusions therefrom is called ray acoustics. The essence of ray theory is the postulate of wave fronts, along which the phase or time function of the solution is constant and the existence of rays that
describe where the sound emanating from the source is being sent to. Like its analogy in optics, ray acoustics has considerable intuitive appeal and presents a picture of the propagation in the form of the ray diagram. Ray theory has certain shortcomings. It does not provide a good solution under conditions where the radius of curvature of the rays or the pressure amplitude changes appreciably over the distance of one wavelength. Practically speaking, ray theory is restricted to high frequencies or short wavelengths.

The other form of solution of the equation is normal mode theory, in which the propagation is described in terms of characteristic functions called normal modes, each of which is a solution of the wave equation. The normal modes are combined additively to satisfy the boundary and source conditions of interest. The result is a complicated mathematical function which, though adequate for computations on a digital computer, gives little insight, compared to ray theory, on the distribution of the energy of the source in space and time. However, normal mode theory is particularly suited for a description of sound propagation in shallow water. Even though normal mode theory can give a complete solution of the wave equation applicable to all conditions of frequency and sound speed gradient, unless simplifying assumptions are made, full solutions of the wave equation including the effects of surface and bottom boundaries, as well as range dependent variation in the sound speed profile are difficult to obtain numerically or analytically. One such simplifying assumption is WKB approximation applicable to a stratified medium, where the sound velocity varies slowly in the vertical. The solution in this case will be in terms of normal
modes. Yet another is the parabolic approximation applicable to a stratified medium where the sound velocity varies slowly in the horizontal also (Tappert, 1977). The condition that the propagation path should remain close to the horizontal is a disadvantage of the latter approximation (Spindel, 1985).

There have been several attempts to modify ray theory (Bucker, 1971; Cornyn, 1973; Weinberg and Zabalgoezcoa, 1977) and normal mode theory (Kanabis, 1972; William, 1981) to accommodate range dependent characteristics of the medium with varied success.

1.2.4. Attenuation

Attenuation of sound in sea water is due to spherical spreading, absorption in the medium and scattering by irregular boundaries, suspended particles, thermal microcells and regions of turbulence. Absorption can be expressed in terms of an absorption coefficient defined as

\[ k = \frac{10 \log I_1 - 10 \log I_2}{r} \]

where \( I_1 \) and \( I_2 \) are intensities at the source and the receiver separated by a distance \( r \).

The surface as well as the bottom of the sea are both a reflector and a scatterer of sound. The degree of scattering depends on the roughness of the surface. A criterion for the roughness is given by Rayleigh's parameter defined as

\[ R = kH \sin \theta \]

where \( k \) is the wave number, \( H \) is the rms wave height and \( \theta \) is the grazing angle.
Extensive measurement of bottom roughness were made in order to characterise scattering regimes (Mackenzie, 1960; Clay, 1966; Hampton, 1974), and models were developed to characterise acoustic scattering from the time varying surface of the sea (Eckart, 1953; Fortuin, 1970). Also there have been several studies on the attenuation characteristics of the boundaries in a shallow water environment (Kuperman and Ingenito, 1977; Louis, 1980; Beebe et al, 1982; Mitchel and Facko, 1983). But theoretical estimation of the attenuation constant requires a detailed knowledge of the medium. Hence the attenuation constant in a region is usually determined by fitting the solution of wave equation to experimental data (Clay and Medwin, 1977).

1.2.5 Other areas of active research

The other areas of active research in underwater acoustics include the acoustic effects of oceanic eddies (Vastano and Owens, 1973; Weinberg and Clark, 1980; Henrick et al, 1980) and fronts (Speindel and Spiesberger, 1981) and the inverse technique to obtain information on bottom parameters (Schwetlick, 1983; Bleistein and Cohen, 1979) and on the mesoscale variations in the ocean (Munk and Wunsch, 1979; Cornuelle, 1983).

1.3 LITERATURE SURVEY

Except for studies carried out in Defence Laboratories, which are of classified nature and pertain to specific objectives, studies on the acoustic characteristics of the seas around the Indian sub-continent particularly coastal waters, have been few in number. There were some studies on the sound velocity structure of certain areas of the Indian Ocean. Fenner and Bucca (1972)
studied the sound velocity structure of the northwest Indian Ocean by analysing the historical temperature - salinity data north of 10°S latitude and west of 80°E longitude. He found that the cause of the complex and irregular sound velocity structure and extremely broad primary sound channel found throughout the Northwest Indian Ocean was due to the intensive mixing between the water masses.

Seshagiri Rao and Sundaranan (1974) studied sound velocity structure in the upper 500m of the Arabian sea during September to December by analysis of the data for the Arabian sea along certain meridional and zonal sections. They found negative velocity gradient in the shallow thermocline, the occasional positive gradients in the surface layer and perturbations in the sound velocity structure in the surface layers especially in the northern sections. Methods for plotting sound ray paths in the potential layers obtained from bathy thermograms have been discussed by Rao (1977). The vertical distribution of temperature influences the sound propagation, particularly in bending the rays from straight line paths. The changes in temperature structure contribute to the formation of several layers with different temperature gradients and plotting of sound ray paths for these bathythermograms becomes difficult. He found a method which reduces the layers in potential layer to a maximum of 3 layers. The small scale features of sound velocity structure in the northern Arabian Sea during February - May (1974) were studied by Somayajulu et al (1980). They have found that the relatively warm and saline Persian Gulf water which intrude into the Arabian sea at 200-400m influence the sound velocity structure and cause formation of an upper sound channel.
Microstructure of sound velocity in the upper 500m of Northern Arabian Sea based on STD data has also been presented by them. The intra-annual variability of the acoustic characteristics of Cochin has been studied by Geetha Bhasker et al (1988). They found sharp negative sound velocity gradients in the surface layers up to 20m depth and almost negligible gradients in the deeper layers during monsoon and post-monsoon seasons suggesting very small horizontal detection ranges in the surface layers and long ranges below 20m. The positive and slightly negative sound velocity gradients found during winter and summer respectively indicate the possibility of comparatively larger range of detection during these seasons, the former season being more favourable. Ramamurthy et al (1990) detailed methods to compute geometric path, travel time and intensity of sound rays and their variability in the Bay of Bengal utilising sound speed data derived from CTD profiles. The results indicated the independent nature of the rays for a given source receiver pair.

The present study comprises of an attempt to elucidate the long range propagation characteristics in shallow waters. There have been various investigations of similar nature in various parts of the world. Kuperman and Ingenito (1977) studied the attenuation of the coherent component of sound propagating in shallow water with rough boundaries. Normal mode theory was used in conjunction with a perturbation method. Numerical results were presented for sample shallow water environment with depth dependent sound speed profiles and loosy bottom sediments. Graves et al (1978) used the adiabatic range variation method to perform an approximate separation into normal modes of the wave equation to study underwater sound propagation in stratified
ocean channel and obtained a solution for the isovelocity ocean wedge with rigid ocean floor.

The upslope propagation characteristics in a wedge shaped ocean by the method of normal mode was also studied by Coppens and Sanders (1978). Jensen and Kuperman (1979) presented an environmental acoustic model with an emphasis on application to coastal waters. They presented simulation studies of propagation over a sloping bottom, seismic propagation and the spatial distribution of surface generated noise. Jensen and Kuperman (1980) studied model cut off during upslope propagation in a wedge shaped ocean using the parabolic equation method. The studies showed that there was very little conversion of energy to the next lower mode and that the propagation in a wedge must include coupling into the continuum. Jensen (1981) studied the sound propagation in shallow water with a detailed description of the acoustic field close to surface and bottom. He compared the data with normal mode prediction for an isovelocity shallow water propagation channel overlying a complicated layered bottom. Excellent agreement was obtained over the range 50-3200Hz for range up to 30km. Beebe Mc Daniel and Rubano (1982) carried out the shallow water transmission loss prediction using the Biot sediment model. Experimental data and predicted propagation loss from the shallow sediments are compared for frequencies from 25 to 800 Hz. Good agreement was obtained between measured 1/3 octave transmission loss values and predicted values for frequencies of 25, 80 and 250Hz.

Propagation of acoustic signals in the sea is influenced by the physical properties of sea water viz. temperature, salinity and
pressure. The results of investigations on the acoustic properties of the coastal waters of Kerala are presented in this thesis. The hydrographical features of the coastal waters of Kerala have been studied by various authors. Ramasastry (1959) investigated the distribution of sea water characteristics in the upper layers of the south eastern Arabia Sea and found that though the seasonal variations below 20m are not very prominent, processes like upwelling and local variations are very important. During upwelling the surface water gets completely replaced by the subsurface waters. Consequently very low temperature and high salinities are encountered at all levels. Ramasastry and Myrland (1959) investigated the distribution of temperature, salinity and density along the south Malabar Coast during the post monsoon season. The hydrographical features of the continental shelf waters of Cochin were studied by Ramamritham and Jayaraman (1960) and Patil et al (1964). They found that under the influence of the prevailing current system the influx of freshwater extends as a tongue of low salinity water for considerable distance from the coast. Hydrography of the surface waters of Kerala has also been studied by Darbyshire (1967). She found a sharp thermocline associated with the Arabian Sea water, which occurs immediately below the surface during summer and sinks a depth of about 100m in winter. Sharma (1968) also investigated the seasonal variations of hydrographic properties along west coast. The UNDP/FAO report (1973) described the monthly and seasonal hydrographic conditions along various sections off Kerala coast. While analysing the physical characteristics of water off the west coast of India during late spring, Varadachari et al (1974) observed a tongue of high salinity water (>36%) extending from the off shore region towards
the coast during late spring. Purushan and Rao (1974) Gopinathan (1974) and Murty and Vishunudatta (1976) also observed vertical movement of isolines in association with upwelling which commences in February along the south west coast of India. In his M.Sc dissertation submitted to the Cochin University, Nandakumar (1983) carried out a study of the hydrological features of the shelf waters along the west coast of India with an attempt to explain their influence upon the living resources of region. He has analyzed the distribution of temperature, salinity and dissolved oxygen along various sections of the Kerala coast during 1972-73 utilising UNDP/FAO data. His studies brought out the influence of upwelling on the hydrographic conditions and fishery in the coastal waters of Kerala. Satish (1984) studied the seasonal variability of the temperature field off the south-west coast of India. He found that though weak during November-March, the monthly mean longshore component of the wind stress is always conducive to coastal upwelling and follows a pattern similar to that of the isotherm tilt. Murthy (1985) analysed the variations in temperature and salinity in relation to upwelling and sinking utilising the UNDP/FAO report data. Hareesh Kumar (1987) presented diurnal scale variability in vertical thermal structure of coastal waters off south west coast of India during May 1985. Heating and cooling cycles observed in the surface layer are qualitatively discussed in terms of surface heat exchange processes.

In addition to the hydrographic parameters, the characteristics of the bottom also influence the propagation of sound in shallow water through absorption, reflection etc. The distribution and characteristics of the sediments along the Kerala coast have been
discussed by various authors. Kurian (1967) has identified the four zones of bottom deposits in the shelf off Kerala coast. A detailed investigation on the topography of sediments of the western and eastern continental shelves around Cape Comorin has been presented by Hashimi et al (1981). The region between Cochin and Quilon was found to be topographically smooth with sediments characterised by a high percentage of fine grained sediments.

1.4 Scheme of the present work

Results of investigations on the inter-annual and intra-annual variability of acoustic propagation characteristics of the coastal waters of Kerala in relation to hydrography and distribution and characteristics of bottom sediments are presented in this thesis.

The thesis is presented in five chapters including the introductory chapter. Chapter-2 discusses the relevant details of data used for the study, the processing method adopted and the method used for the computation of sound velocity in water. The theoretical details of the computational aspects used for the study of long range propagation characteristics are also presented in this chapter. The results of the investigation on the inter-annual and intra-annual variations of temperature, salinity and sound velocity in the coastal waters of Kerala are discussed in Chapter-3. A discussion on the variability of high frequency propagation characteristics in the region is presented in Chapter-4. Chapter-5 presents the methodology used for the computation of transmission loss in a wedge-shaped ocean. It
also discusses the results of the investigation on the long range propagation characteristics of the coastal waters of Kerala. A summary of the thesis and conclusions drawn from the present study are presented in Chapter-6.