CHAPTER III
TEMPORAL AND SPATIAL VARIABILITY OF SOUND VELOCITY IN THE COASTAL WATERS OF KERALA

3.1 Introduction

The influence of temperature, salinity and depth on sound velocity has already been discussed in detail in the preceding chapter. In response to the changing monsoons, the coastal waters of Kerala exhibit considerable temporal and spatial variability in temperature and salinity. Under its influence, the sound velocity also exhibits large variations both in space and time. This chapter attempts to bring out the nature of variations in sound velocity and their dependence on hydrographic conditions in the coastal waters of Kerala. The parametric variability has been studied along the three sections, off Quilon, Cochin and Kasargode, during 1972 and 1973 on the basis of monthly distribution of the parameters.

3.2. MATERIAL AND METHODS

The data on temperature and salinity collected in different months during 1972-73 are used in this study. The details of the data have already been discussed in the previous chapter. The processing of temperature and salinity data has also detailed in the earlier chapter. Sound velocities are computed using the method discussed in section 2.3.

Vertical sections of temperature, salinity and sound velocity are drawn for different months during, both the years. They are presented as fig. 2 to 18.
3.3 RESULTS AND DISCUSSION

3.3.1 Spatial and Temporal variations of vertical profiles of sound velocity in relation to temperature and salinity.

Vertical profiles of sound velocity have been prepared for three sections namely Quilon, Cochin and Kasargode during different months of 1972 and 1973. 1972 has been a conspicuously drought year, while 1973 experienced normal rainfall. During March 1972, the maximum value of sound velocity at the surface is above 1542 m/s off Quilon and Cochin while off Kasargode, very near the coast, values above 1544 m/s are observed (fig. 2). The overall vertical sound velocity gradient is negative in most of the regions with values around 0.06 m/s/m off Quilon and 0.01 m/s/m off Kasargode. Off Cochin, however local positive gradients are also observed with a value around 0.03 m/s/m.

During this month the overall vertical temperature gradient is negative (around 0.04°C/m off Quilon and Kasargode 0.04°C/m off Cochin). The isotherms show slight downward slope towards the coast indicating a weak sinking process. (Geetha Bhasker et al. 1988), comparatively low values of salinity (33.5 to 34.5) are observed in all the sections in the surface layers. However, salinity values above 35 are seen below 45m off Cochin and Kasargode. The positive gradient in sound velocity observed locally off Cochin irrespective of the negative temperature gradient may be attributed to the larger vertical variations in salinity which swamps the effect of the small negative temperature gradient. The effect of large vertical variation in salinity is clearly seen off Kasargode also where the negative sound veloci-
Fig. 2 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s - 1500) during March 1972.
ty gradient is extremely small even though the negative temperature gradient is comparatively large.

It is interesting to note that the influence of the conspicuously drought conditions of 1972 is clearly indicated in the vertical profiles of 1973 as can be seen by comparing fig. 2 (March 1972) and fig. 3 (March 1973). During March 1973, the surface sound velocity increases to value above 1543 m/s off Quilon and to values above 1546 m/s in the other two sections in response to increasing temperatures. Both the temperature and salinity values are substantially larger in 1973 compared to 1972. Weak monsoon condition result in less evaporation and consequently less heat energy loss. Hence the heat energy stored in the ocean, normally in the mixed layer increases after a monsoon failure (George and Ramasastry, 1975). This increase in stored heat energy manifests itself as a temperature increase in the mixed layer. Thermal stratification is better in March 1972 compared to 1973 March, when well formed mixed layers are observed in all the three sections. Off Quilon the vertical sound velocity gradient is slightly positive, but it is negative off Cochin and Kasargode. Off Quilon the vertical temperature gradient is marginally negative up to about 20m depth and marginally positive below. Off Cochin and Kasargode, the temperature gradients are negative and of small magnitude. The isolines slope down towards the coast indicating coastal sinking.

During April 1972 (fig. 4) the overall vertical gradient of sound velocity is 0.1 m/s/m in the sections. The maximum value of sound velocity at the surface has increased from the March value to 1545 m/s. Summer heating increases the surface temperature to
Fig. 3 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during March 1973.
Fig. 4. Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during April 1972.
about 30° in the three sections with maximum vertical temperature gradient of about 0.05° c/m. There is a general increase in salinity compared to the previous month in the three sections, particularly off Quilon, probably due to the weak upwelling as indicated by the slight slope of the isolines up towards the coast (UNDP/FAO report, 1973). The salinity decreases away from the coast as a result of the diverging flow associated with upwelling.

Fig. 5 depicts the vertical profiles of sound velocity temperature and salinity during April 1973 in the section off Quilon. It has not been possible to illustrate the profiles off Cochin and Kasargode due to paucity of data. Compared to the previous month, the surface sound velocity increases to a value above 1546 m/s as a result of the increase in surface temperature to values above 30°c. The sound velocity decreases with depth and the magnitude of gradient is around 0.09 m/s/m. The magnitude of temperature gradients is about 0.05°C/m. The salinity is nearly uniform but indicates marginal increase from the previous month. Both temperature and salinity values are higher compared to corresponding month in the previous year. The isoline slope up towards the coast indicating coastal upwelling.

Fig. 6 & 7. show the vertical profiles of sound velocity, salinity and temperature off Cochin and Quilon during May 1972 and 1973. Profiles of Kasargode have not been depicted due to paucity of data along this section. The sound velocity in the surface layers shows lower values compared to April 1972, in response to decrease in surface temperature and salinity. The maximum value of sound velocity in the surface is around 1543 m/s. Off Cochin, the surface sound velocity doesn't indicate
Fig. 5 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during April 1973.
Fig. 6 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500), during May 1972.
Fig. 7 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during May 1973.
increase eventhough there is an increase in surface temperature. This can be attributed to the large reduction in the values of salinity in this region as a result of the large run off from land caused by the temporary onset of monsoon over Kerala on May 13, 1972 (George and Ramasastry, 1975). The sloping of the isotherms indicate comparatively stronger upwelling than during the preceding month. The upwelling causes the salinity in the area to increase to a value above 35 except very near the coast where the surface salinity is lowered due to run off from the land.

Off Quilon, the surface sound velocity decreases towards the coast as a result of large reduction in salinity in this region. Near the coast, off Cochin and Quilon, the maximum value of sound velocity at surface is less than 1539 m/s. The maximum overall sound velocity gradient off these stations is as high as 0.2 m/s/m consequent to increase in the overall vertical temperature gradient. However upwelling maintains large vertical gradients in temperature below about 10m off both Quilon and Cochin.

Owing to the rough sea conditions that exist during the monsoon season, data on hydrographic parameters are highly scarce during June, July and August. Off Kasargode, during June 1972 (fig.8) the sound velocity at the surface varies between 1534 m/s and 1543 m/s. The surface sound velocity shows conspicuous decrease towards the coast in association with the large shoreward decrease of surface salinity. Salinity is generally above 35, except very near the coast values less than 31 are observed, which may be due to mixing of run off from land. The overall vertical sound velocity gradient is about 0.15 m/s/m. The
Fig. 8 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during June and July 1972.
surface temperature near the coast is below 28°C and increases towards offshore. The entire water column up to about 40m depth shows isothermal conditions below which the temperature decreases rapidly.

It is interesting to note that the surface sound velocity during June 1973 (fig. 9) shows marked decrease compared to the previous months off Quilon and Kasargode the maximum being about 1544 m/s. The overall vertical temperature gradients show an increase in both the sections, the values being 0.09 °C/m and 0.14°C/m for the sections off Quilon and Kasargode respectively. The isotherms slope up towards the coast indicating coastal upwelling. Consequent to this increase in temperature gradient, sound velocity gradient also increases showing overall values of 0.16 m/s/m and 0.32 m/s/m off along these sections. Off Kasargode surface sound velocity shows decrease towards the shore in association with corresponding decrease in salinity.

Comparison with the June conditions in 1972 shows an increase in the surface sound velocity values during June 1973. There is a sharp increase in the sound velocity gradient compared to the corresponding month of the preceding year. The temperature values in the mixed layer are higher in 1973 than in 1972. The temperature gradients, however, are much sharper in 1973. The salinity values are generally higher in 1973. The hydrographic conditions clearly indicate influence of the monsoon failure during the preceding year and comparatively good monsoon conditions in 1973. (Abbi et al 1974).

Off Cochin, during July 1972, (fig.8) the maximum surface sound velocity is around 1539 m/s. Off Quilon, the maximum surface
Fig. 9 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s - 1500) during June and July 1973.
sound velocity is found to have reduced to 1541 m/s, consequent to reduction in surface temperature. In both the sections, the overall sound velocity gradient is found to be 0.2 m/s/m. Larger values of gradients are observed only below 10m. The overall sound velocity gradient doesn't indicate any variation compared to May 1972.

Off Cochin during July 73 (Fig. 9) surface sound velocity shows decrease to about 1541 m/s in association with decrease in the surface temperature. Very near the coast surface sound velocity is as low as 1535 m/s. The overall vertical temperature gradient has increased to 0.17° c/m. The temperature gradient below the surface layer is much sharper compared to the May conditions as a result of the intense upwelling indicated by the upward tilt of the isotherms. Consequent to the increase in temperature gradient, the sound velocity gradient also increase to an overall value of 0.38 m/s/m. The salinity values decrease particularly in the surface layers as a result of the monsoon rainfall.

Comparison with the July conditions in 1972 shows that during 1973 the surface sound velocity is higher consequent to the higher temperature induced by the drought conditions of the previous year. The sound velocity gradient is however sharper during 1973 than the preceding year. The salinity values are also generally higher in 1973.

Fig. 10 shows the conditions that existed off Kasargode in August 1972. The value of sound velocity at the surface is generally less than 1540 m/s. The minimum value of sound velocity at the surface (less than 1538 m/s) is associated with the minimum salinity. The temperature gradient is very strong in the surface layer up to 30m. Here the velocity line is also very sharp with a
Fig. 10  Vertical profiles of temperature ($^\circ$C), salinity (S.I. Units), sound velocity (values in m/s-1500) during August 1972.
gradient of about 0.5 m/s/m. Below 30 m (where isothermal watermass is observed) the sound velocity gradient is extremely small. Ramasastry and Myrland (1960) have attributed the formation of this watermass to the mixing of upwelled water with the bottom current. A similar condition with sharp temperature gradient in the surface layers and isothermal watermass near the bottom has been reported in a section off Cochin during August 1958 by Geetha Bhasker et al (1988). Salinity values are generally lower than 35 and very low values less than 33 are found in the surface layers.

Fig. 11 presents the vertical profiles of sound velocity, temperature and salinity during August 1973 off Quilon and Kasargode. Corresponding to the general decrease in surface temperature, the surface sound velocity also shows a decrease compared to the earlier months. Off Quilon, the surface sound velocity increases towards the coast (from 1539 m/s at 16 km offshore to 1542 m/s nearshore). Off Kasargode, the surface sound velocity decreases towards the coast (from 1532 m/s 32 km offshore to 1528 m/s near the shore). This is due to increase of surface temperature towards the coast off Quilon and decrease of surface temperature towards the coast off Kasargode. The overall value of vertical temperature gradient off Quilon has increased approximately to 0.13° c/m compared to the earlier observations. Consequently the sound velocity gradient also increases to about 0.3 m/s/m. Off Kasargode, however, the overall value of temperature gradient has decreased to 0.1°c/m and consequently the sound velocity gradient also decreases to 0.2 m/s/m compared to the earlier observations. Off both Quilon and Kasargode, the sharpest gradient are found below about 10m. Off Kasargode, the gradient are less sharp
Fig. 11 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s -1500 during August 1973.)
compared to June value. While the values of salinity off Quilon have slightly reduced, the reduction in salinity off Kasargode is considerable, particularly in the surface layers.

A comparison of the vertical profiles off Kasargode between August conditions of 1972 and 1973 bring out the influence of the stronger monsoon during 1973 on sound velocity and hydrography. The intense upwelling has resulted in considerable lower surface temperatures with smaller gradients. Accordingly the sound velocity shows comparatively lower surface values during 1973 with smaller vertical gradients.

During September 1972 (fig. 12), the surface sound velocity increases to a value around 1541 m/s off Quilon, Cochin and Kasargode consequent to increase in the surface temperature. Sharp thermocline and velocline near the surface and nearly isothermal water below are observed in these region. Off Quilon the thermocline and velocline become sharper towards the coast and near the coast, they are limited to within 20m from the surface. The maximum values of sound velocity gradient and temperature gradient are 0.55 m/s/m and 0.25° c/m respectively. Off Cochin and Kasargode, both thermocline and velocline are limited to a depth of about 10m from the surface. The maximum values of sound velocity gradients and temperature gradients are 1.1 m/s/m and 0.5° c/m respectively. Both thermocline and velocline are the sharpest during the month of September. There is an increase in salinity due to decrease in rainfall and the continued upwelling indicated by the upward slope of the is lines towards the coast.
Fig. 12 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during September 1972.
The vertical sections of sound velocity and hydrography off Kasargode during September 1973 are illustrated in (fig. 13). The surface sound velocity increases from the August values to nearly 1534 m/s. Along the surface, sound velocity decreases towards the coast to values as low as 1530 m/s. This is due to shoreward decrease of salinity caused by surface dilution. Compared to the earlier month, the overall values of sound velocity gradient and temperature gradient have increased to 0.30 m/s/m and 0.15°c/m. The largest gradient is found very near the surface and up to a depth of around 15, below which a nearly isothermal water is observed, indicating that both thermocline and velocline are close to the surface during this month. Salinity values have generally reduced from their previous values in August.

Comparing the vertical distributions during September of 1972 and 1973, it can be found that the surface sound velocity is considerably lower during 1973 consequent to the hydrographic conditions. The vertical sound velocity gradient is also considerably lower in 1973.

During October 1972, the section off Cochin (Fig. 14) shows that the surface value of sound velocity has increased to about 1543 m/s consequent to increase of the surface temperature to values above 29°C, compared to the previous month. The thermocline and velocline are observed about 10m below the surface with their sharpness considerably reduced compared to September 72. The sound velocity gradients and temperature gradients have overall values of 0.25 m/s/m and 12°c/m respectively. The isothermal water observed during September 72
Fig. 13 Vertical profiles of temperature (°C), salinity (S.I.Units), sound velocity (values in m/s-1500) during September 1973.
Fig. 14 Vertical profiles of temperature (°C), salinity (S.I.Units), sound velocity (values in M/s-1500) during October 1972.
in the bottom layers in this region is now practically absent as a result of sinking indicated by the downward slope of the isotherms towards the coast. This sinking is initiated by the change in wind direction and the consequent changes in coastal circulation normally observed during this period of the year. (Geetha Bhasker et al (1988). Salinity distribution remains more or less the same as in September 1972. Generally, values above 35 are observed except very near the coast where salinity is less than 33.

The vertical profiles of sound velocity, temperature and salinity off Quilon and Cochin during October 1973 are depicted in fig. 15. Sound velocity at the surface is found to increase compared to the previous month, both off Quilon and Cochin, reaching maximum values above 1542 m/s. Off Quilon, sound velocity decreases towards the coast reaching minimum value of around 1538 m/s very near the coast, in association with shoreward decrease in surface temperature. The vertical gradients in sound velocity also shows a decreasing trend temporally with values around 0.2 m/s/m off Quilon and 0.06 m/s/m off Cochin. Salinity values show a general increase in both the sections.

Comparing with the conditions that existed during the corresponding month of the previous year, it can be seen that surface temperature, surface salinity and the sound velocity at the surface are lower in October 1973. The vertical gradients of the parameters are also lower during this year.

The vertical profiles of the parameter during 1972 November off Quilon and off Cochin are illustrated in Fig. 16. The maximum
Fig. 15 Vertical profiles of temperature (°C), salinity (S.I.Units), sound velocity (values in m/s-1500) during October and November 1973.
Fig. 16 Vertical profiles of temperature (°C), salinity (S.I. Units), sound velocity (values in m/s-1500) during November and December 1972.
values of surface sound velocity have increased to values around 1546 m/s in the section off Quilon and off Cochin as a result of increase in surface temperature to above 30°C. No sharp gradients in temperature and sound velocity are observed. In sections off Quilon the overall values of vertical gradients of sound velocity and temperature are 0.08 m/s/m and 0.05°C/m respectively. However, off Cochin nearly isothermal water is observed up to a depth of 40 m with negligible gradient in sound velocity caused by sinking of the surface water. The salinity values are also reduced to below 35 as a result of this sinking process.

Fig. 15 and 17 present the vertical profiles of temperature salinity and sound velocity that prevailed during 1973 November. The surface sound velocity shows a temporal increase reaching 1544 m/s off Cochin and 1541 m/s off Kasargode, consequent to the increase in surface temperature to above 29°C and 28°C respectively. Corresponding to decrease in temperature gradients the sound velocity gradient also decreases to 0.04 m/s/m and 0.2 m/s/m off Cochin and Kasargode respectively. The vertical profiles show that salinity continues to increase off Kasargode while it decreases off Cochin under the influence of sinking.

Comparison with the conditions that observed during the previous year shows that the sound velocity and the hydrographic parameter are lower during 1973. The vertical gradients are also lower during the latter year.

During December 1972, the surface sound velocity continues to show the increasing trend reaching values above 1543 m/s off Kasargode with very small vertical gradient (fig. 16). Nearly
Fig. 17 Vertical profiles of temperature (°C), salinity (S.I.Units), sound velocity (values in m/s-1500) during November 1973.
Isothermal water is observed up to a depth of 40m. The thermocline and velocline are no longer observed close to the surface. The complete breaking up of the profiles which existed till October has been brought by the sinking process, indicated by the downward slope of the isotherms. Salinity shows a decreasing trend under the influence of the sinking process.

The vertical profiles off Quilon and Cochin during January 1973 (fig. 18) show decrease in surface sound velocity brought about by the winter cooling to values around 1541 m/s (off Quilon) and 1545 m/s (off Cochin). A well formed mixed layer is seen with an overall positive vertical temperature gradient of about 0.01°C/m off Quilon. Off Cochin the temperature gradient is comparatively large and negative up to a depth of 30m below which a weak positive gradient is observed. Because of the better thermal stratification in the surface layers off Cochin the magnitude of the overall temperature gradient is larger and is around 0.05°C/m. The salinity decreases slightly from its November value off Quilon and Cochin. In the vertical direction salinity is nearly uniform off Cochin whereas off Quilon salinity increase from about 34 at the surface to about 35 at the bottom. The increase in salinity towards the bottom coupled with the positive temperature gradient causes the sound velocity gradient to the positive and of comparatively larger magnitude of about 0.05 m/s/m. However, during December-January 1958-59, the presence of positive gradients of temperature and sound velocity have been reported off Cochin by Geetha Bhasker et al (1988).

Off Kasargode, during February 1973 (fig. 18) the surface sound velocity is about 1543 m/s. The temperature gradient is negative
Fig. 18 Vertical profiles of temperature (°C), salinity (S.I.Units), sound velocity (values in m/s - 1500) during January and February 1973.
with negligible magnitude. The salinity is nearby uniform in the entire water column the sound velocity gradient found to be positive, despite, the temperature gradient being marginally negative, the magnitude however is negligibly small.

3.3.2 Overall features of variations in sound velocity and hydrography.

The monthly as well as annual variation in the vertical profiles of sound velocity and hydrographic parameters off Quilon, Cochin and Kasargode have been discussed in the forgoing section. It will be interesting to summarise the overall features of the variations in the vertical profiles of these parameters to arrive at the seasonal patterns of the variations. Low values of surface temperature and sound velocity are observed during the monsoon season and high values in the summer season. The surface temperature and sound velocity show a bimodal distribution with two maxima and two minima in a year. In the section off Quilon and Cochin the maxima occur in April and November and minima in February and August. Off Kasargode, however, the summer maximum occurs in May.

The magnitude of the lowest value of surface temperature and sound velocity are found to depend on the monsoon, the stronger the monsoon the lower the magnitudes. Also the highest values of temperature and sound velocity appear to depend on the monsoon of the previous year, the weaker the monsoon in the previous year, larger the highest values. The maximum and minimum values occurring in November and February also depend on the strength of the monsoon, a weak monsoon resulting in higher maximum in November and higher minimum in February. Similarly, the temperature and
sound velocity in the mixed layer above the thermocline is found to be higher after a weak monsoon. The isotherms slope up towards the coast from April to the end of September indicating coastal upwelling, while they dip towards the coast from October to the end of March indicating coastal sinking.

The nature of variation of salinity is seen to be more complex. The surface salinity variation show two maxima and two minima in a year. The maxima usually occurs in June and by the end of the year, whereas, the minima occurs in March and by the end of Southwest monsoon season. The salinity values are seen to be generally higher after a weak monsoon.

Vertical gradients of temperature and sound velocity are found to be small in magnitude from the beginning of the year up to the end of April. During this period both positive and negative values are observed. Generally negative gradients are seen from May to October. Sharpest gradients are seen in the bottom layer up to July which rise to the surface by August and persists till the end of September. In October the sharpest gradients are at mid depths. By the end of October or early November this temperature and sound velocity structure is completely broken up and the gradients are small in magnitude. Generally their values are negative in November and positive in December. The gradients are seen to depend on the strength of the monsoon, the stronger the monsoon the sharper the gradient.