CHAPTER II
SEASONAL VARIATION OF TEMPERATURE AND DENSITY OFF THE WEST AND EAST COASTS OF INDIA

The analysis of temperature and density have immense importance in the study of upwelling and sinking. Variations in upwelling and sinking will be reflected in the temperature and density fields. In this chapter the seasonal variation of temperature and density at different localities off the west and east coasts of India are presented and the surface and subsurface currents are inferred from the slope of isotherms and isopycnals. No conclusions are drawn regarding upwelling and sinking since these are dealt in separate chapters.

Temperature and density fields off the west coast of India

Vertical sections of temperature and $\sigma_t$ are prepared off Quilon ($8^\circ50'N$), off Cochin ($10^\circ00'N$), off Kasaragod ($12^\circ31'N$) and off Karwar ($14^\circ47'N$). Two sections off Ratnagiri ($16^\circ59'N$) are also presented.

2.1. Vertical sections of temperature and $\sigma_t$ off Quilon (along $8^\circ50'N$):

Vertical sections of temperature and $\sigma_t$ off Quilon are presented in Figs.1-10. The section along $8^\circ50'N$ were covered during the period March 1964 to October 1964. Due to lack of data for November and December it could not be
presented. For January and February sections along 9°00'N are utilised.

2.1.1. March

The isotherms and isopycnals slope up towards the coast from about 90 km indicating a southerly current in the upper 100 m (Fig. 1). The downward tilt of isopycnals towards the coast represents a northerly current in the layers below 100 m. The depth of mixed layer is about 90 m and the surface temperatures are fairly high over 29°C.

2.1.2. April

The depth of the mixed layer decreases during April compared to that present in the previous month, though the surface temperature has increased to over 30°C (Fig. 2). The upward tilting of isotherms and isopycnals towards the coast is marked suggesting a strengthening of the southerly flow. The offshore-onshore density gradient is positive above 80 m but it is very weak.

2.1.3. May

The isotherms and isopycnals continue to slope more and more towards the surface indicating a continued increase in the strength of the southerly current in the
FIG.1. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_z (g/k)$

ALONG 8° 50'N, MARCH 7, 1964.
FIG. 2. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ (g/l)

ALONG 8°50'N, APRIL 6, 1964.
FIG. 3: VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ (g/l)

ALONG 8°50'N, MAY 10-11, 1964.
A weak northerly flow below 100 m in the continental slope is also evident. The surface temperature is above 29°C and the thermal structure shows a negative gradient towards the coast between 20 and 85 m. A decrease in temperature and an increase in density at all depths above 200 m are noticed during the period April to May and this variation is conspicuous between 50 and 100 m. The depth of mixed layer is about 60 m in nearshore regions and it increases offshore.

2.1.4. June

The surface temperature drops considerably from May to June. It is slightly above 26°C near the coast and gradually increases offshore (Fig.4). The orientation of isotherms and isopycnals suggests a southerly current in the surface layers and a weak countercurrent below 60 m. The thermocline is observed very near the surface and the depth of mixed layer increases offshore. A decrease in temperature and an increase in density are found in the upper 200 m between May and June, and the decrease of temperature is conspicuous in the depth range of 20 to 75 m.

2.1.5. July

The thermocline reaches the surface in nearshore regions (Fig.5). Several of the isotherms do even outcrop into the naviface. The surface temperature is less than
FIG. 5. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ (g/l)

ALONG 8°50'N, JULY 9-10, 1964.
24°C near the coast and increases offshore. The upsloping of isotherms and isopycnals towards the coast suggests a strong southerly flow and a subsurface countercurrent is indicated below 150 m. Although there is a decrease of temperature at all depths from June to July, the density in the upper 10 m decreases due to heavy rains and river discharge. The offshore-onshore temperature gradient is negative in the upper layers and strongest at about 30 m.

2.1.6. August

During this month the upsloping of isotherms and isopycnals towards the coast is less marked compared to July indicating a weakening of the southerly current in the outer shelf (Fig. 6). In the inner shelf region the flow is weak northerly. The surface temperature in nearshore and offshore regions are below 26°C and the thermocline is found very close to the surface. Between July and August, there is a slight increase in temperature at the surface and at subsurface depths.

2.1.7. September

There is an increase in temperature and a decrease in density at all depths in the continental shelf and slope region compared to the previous month (Fig. 7). The density distribution suggests a strong southerly current in offshore
Fig. 6. Vertical sections of (a) temperature (°C) and (b) f of 85°N.
Along 85°N, August 6-12, 1964.

→ Depth in metres
regions, but in nearshore regions the flow is weak northerly in the upper 30 m. The surface temperatures are above 26°C and the depth of the mixed layer is about 40 m in the continental shelf.

2.1.8. October

The oceanographical conditions change considerably from September to October. Near the coast, the surface temperature is below 25°C and increases offshore (Fig.8). The surface flow is southerly, but below 50 m a counter-current is indicated. The thermocline is observed at the surface in the continental shelf. An increase in density and a decrease in temperature at all depths occur from September to October, and they are conspicuous in the upper 50 m of the continental shelf.

2.1.9. January

In this month the isopycnals slope down towards the coast indicating a northerly current in the nearshore regions (Fig.9). The depth of mixed layer is more than 100 m in the nearshore and slightly less in offshore regions. The surface temperatures are uniform - over 27°C.

2.1.10. February

The condition in the surface layers continues to be the same as in January (Fig.10). However, below 75 m
FIG. 9. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ (g/l)

ALONG 9°00'N, JANUARY 7, 1965.
the isotherms and isopycnals slope up towards the coast which suggest a southerly current in that region, though the surface current is a weak northerly. An increase in density and a decrease in temperature are evident below 75 m from January to February.

2.2. Vertical sections of temperature and $\sigma_t$ off Cochin:

For the present study oceanographic data collected during April 1964 to March 1965 are used (Figs.11-22). Due to unavailability of data for November and December of 1964 the previous years data are used. Except for November and December the data were collected along $10^\circ$OC'N, whereas for November and December the stations were occupied in a direction almost perpendicular to the coast.

2.2.1. April

The isotherms and isopycnals slope up towards the coast indicating a southerly current in the surface layers and a weak northerly current is indicated between 75 m and 100 m (Fig.11). The surface temperature is above 30°C and is fairly uniform in nearshore and offshore regions. The depth of mixed layer is about 90 m in the continental slope region and it increases offshore.

2.2.2. May

The baroclinic field is well developed by May (Fig.12). In the nearshore regions the isotherms
FIG. 11. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t (g/cm^3)$ ALONG 10° 00' N, APRIL 8, 1964.
and isopycnals show marked upsloping indicating a stronger southerly current than in April. The surface temperature continues to be above 30°C, but the depth of mixed layer has decreased considerably in the nearshore regions compared to April to a value of about 60 m in nearshore regions and increases offshore. Between 50 and 150 m a general decrease in temperature and an increase in density is observed from April to May. The downward tilting of isopycnals towards the coast below 120 m indicates a northerly current in that region.

2.2.3. June

By June the nearshore surface temperature decreases to less than 26°C (Fig.13). The surface temperature increases to 28°C at about 45 km from the coast. The thermocline is found almost at the surface in the continental shelf. The marked upsloping of isotherms and isopycnals towards the coast indicates a strong southerly current. Below 80 m, a countercurrent along the continental slope is again indicated. Above 200 m considerable decrease in temperature and increase in density are noticed from May to June and they are more prominent in nearshore regions. The offshore-onsshore temperature gradient is negative from about 100 km in the upper 75 m.
FIG. 13. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_z$ (g/l)

ALONG 10° 00' N, JUNE 10-11, 1964.
2.2.4. July

By July the surface temperature is lowered further both in nearshore and offshore regions (Fig.14). Near the coast the surface temperature is about $24^\circ$C and it increases to about $27^\circ$C at 45 km. The marked upward tilting of isotherms and isopycnals suggests a strong southerly current in the surface layers. The isotherms and isopycnals slope down towards the coast indicating a countercurrent below 110 m. The density structure suggests strong stratification in the upper 10 m in the inner continental shelf. The isotherms and isopycnals are pushed up towards the surface from June to July and several of the isotherms outcrop into the naviface. The offshore-onshore temperature gradient is negative above 100 m but strong gradients are confined to the upper 30 m of the continental shelf.

2.2.5. August

For this month the observations are mainly confined to the continental shelf only (Fig.15). In this region the surface temperature is further lowered in the entire continental shelf to values less than $26^\circ$C, while near the coast it is even less than $24^\circ$C. The upsloping of isotherms and isopycnals are less, compared to that in July, but the surface flow continues to be
FIG. 14. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) θ (°N)

ALONG 16°00' W, JULY 14, 1964.
southerly. Low density water is observed in the surface layers in the entire continental shelf, below which there is not much variation in the oceanographic conditions from July to August.

2.2.6. September

There is an increase in temperature and a decrease in density at all depths above 300 m from the previous month (Fig. 16). The surface temperature is slightly above 26°C and there is no significant onshore-offshore variation. The mixed layer is about 20 m deep in nearshore regions. The slight upsloping of isopycnals indicates a weak southerly current in the surface layers, but between 75 and 150 m the flow is northerly. The presence of low density water is evident in the upper 10 m of the nearshore regions.

2.2.7. October

By October the temperature at all depths decreases again, and a corresponding increase in density is also observed (Fig. 17). The nearshore sea surface temperature is less than 26°C and it increases towards offshore. In the nearshore and offshore regions the thermocline is found almost at the surface. The upward tilting of isotherms and isopycnals towards the coast indicates a southerly current in the surface layers. Below 50 m, a subsurface
FIG. 17. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ (g/l). 

ALONG 10°00'N, OCTOBER 12, 1964.
countercurrent is evident though not so strong as in September. The isotherms and isopycnals are displaced to upper levels considerably from September to October.

2.2.8. November

A drastic change occurs between October and November (Fig.18). The isotherms and isopycnals slope downward from 70 m down to 300 m which suggests a northerly current in this region. The temperatures in the surface layers are increased to 28°C and the mixed layer is more than 100 m. At all the observed depths the density has decreased considerably from October to November while the temperature is increased and the changes are more prominent in the nearshore regions.

2.2.9. December

The conditions in the surface layers do not show much variation from those of November except that there is a slight decrease in the depth of mixed layer (Fig.19). The downward sloping of isopycnals towards the coast is less prominent possibly because the surface current becomes considerably weak. Below 120 m the flow is weak southerly.

2.2.10. January

The isotherms and isopycnals tilt down towards the coast indicating a northerly current (Fig.20). Unlike
FIG. 18. VERTICAL SECTIONS OF (A) TEMPERATURE (°C) AND (B) $\sigma_T$ (g/l)

OFF COCHIN, NOVEMBER 18, 1963.
FIG. 20. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) SALT (g/l)
ALONG 10° 00' N. JANUARY 1885.

DEPTH IN METRES
the southerly current in June-July this current is extended to a depth of about 300 m. The surface temperatures are about 28°C and the depth of mixed layer is about 90 m in nearshore regions. The low density of the surface layers indicates the presence of low salinity water in this region.

2.2.11. February

A slight decrease in surface temperature is observed in this month compared to the previous month (Fig.21). However, the depth of mixed layer increases to 110 m in the continental slope. The isopycnals show a downward sloping towards the coast in the upper 100 m indicating a northerly current, below which the current is weak southerly.

2.2.12. March

The surface temperature has increased to above 29°C in nearshore regions by March, while in the offshore regions the temperature is slightly less, but above 28°C (Fig.22). The depth of mixed layer is more than 100 m and the temperature gradient in the thermocline is sharp compared to that in the previous month. The isopycnals in the upper 100 m slope down towards the coast indicating a northerly current, but below 100 m the current is southerly. There is an increase in temperature between February and March in the upper 100 m. However, there is a decrease of temperature by about 3°C at 150 m and an increase i
FIG. 21. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_t$ ($g/\text{cm}^2$)

ALONG 10° 00' N, FEBRUARY 7-8, 1965.
**Fig. 22.** Vertical sections of (a) temperature (°C) and (b) \(\sigma_t \) (°C)

Along 10° 00' N, March 11-12, 1965.
Fig. 23. Isopleth showing the seasonal fluctuations in the mean temperatures in the section off Cochin. (From Anon., 1973)
density is also observed. The isotherms in the middle and lower thermocline are pushed up from February to March.

2.3. **Time series of temperature during 1971-1972:**

The time series section off Cochin is presented in Fig.23. The figure is reproduced from Anon. (1973). In subsurface layers, a lowering of temperature or upward displacement of isotherms starts from February to March. The temperature at all depths shows a minimum during July in 1971, whereas in 1972 the minimum temperatures are attained in August. The surface temperature begins to fall from June. In 1971 a sudden increase of temperature at all depths occurs between October and November while the increase is gradual in 1972. There is not much variation in the thermal field during the period December to February and the temperature in the surface layers is uniformly high.

2.4. **Vertical sections of temperature and $\sigma_t$ off Kasaragod:**

The section off Kasaragod was covered in 1974 as a part of the Pelagic Fishery Survey. Oceanographic data were collected in seven series - January, March, May, July, August, November and December (Figs.24-30). The stations were occupied at intervals of about 10 miles in the continental shelf region and about 25 miles beyond the shelf. The figures are reproduced from Anon. (1976).
2.4.1. January

The isotherms and isopycnals run almost parallel to the surface from offshore to onshore, but near the coast a slight downward sloping is observed which indicates a weak northerly current (Fig. 24). The depth of thermocline is about 80 m, and the surface temperatures are above 28°C. The pycnocline is well developed in the depth range of 40–100 m which suggests strong stratification. The low density water in the surface layers indicates the presence of low salinity water in this region.

2.4.2. March

A strong baroclinic field is observed during this month (Fig. 25). The isotherms and isopycnals show upsloping towards the coast indicating a southerly flow between stations I and IV, but further offshore the flow is still northerly. The surface layers are warmer than in January, but the depth of mixed layer is reduced considerably, especially near the coast. The density increases from January to March while temperature decreases at all depths except in the upper layers. The isopycnals show a slight downward tilting towards the coast indicating a weak northerly countercurrent below 150 m.
Fig. 24. Vertical sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaragod, January 19, 1974 (from Anon., 1976).
Fig. 25. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaragod, March 14, 1974 (from Anon., 1976).
2.4.3. May

The coastal current from the surface to about 90 m is southerly (Fig.26). The tilting of isopycnals on the shelf area is approximately the same as in March, but a general upward displacement of isopycnals above 150 m is observed. The mixed layer is shallow in nearshore regions, but the depth of mixed layer gradually increases towards offshore. The surface temperature is still relatively high, about 29–30°C. The downward slope of isopycnals at the edge of the continental shelf indicates a northerly current below 100 m.

2.4.4. July

The temperature of the surface layer decreases considerably to about 27°C both in the nearshore and offshore regions (Fig.27). Near the coast, the thermocline and pycnocline are found close to the surface. The depth of mixed layer gradually increases offshore. The upward tilting of isotherms and isopycnals towards the coast in the upper layers suggests a southerly current. Further upward displacement of isotherms and isopycnals are evident above 200 m during the period May to July. A narrow countercurrent below 80 m in the continental slope region is again indicated.
Fig. 26. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaragod, May 15, 1974 (from Anon., 1976).
Fig. 27. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaragod, July 14, 1974 (from Anon., 1976).
2.4.5. August

The surface temperature further decreases to about 26°C in the continental shelf (Fig.28). Near the coast the thermocline and pycnocline are observed at the surface. The surface flow is southerly. Further upward displacement of isotherms and isopycnals are evident between July and August. A countercurrent along the continental slope is also indicated, but unlike in July it is found as a deep reaching flow.

2.4.6. November

The upsloping of isotherms and isopycnals is more marked than in August, indicating a stronger southerly current between stations I and IV, but further offshore the flow is weak northerly (Fig.29). A slight increase in temperature and a decrease in density are observed at all levels above 150 m. In the nearshore regions the surface temperature is about 26°C and increases with distance from the coast. The countercurrent at the shelf edge is evident, but it is not so strong as in August.

2.4.7. December

A dramatic change occurs between November and December (Fig.30). The isotherms and isopycnals slope down towards the coast indicating a northerly current.
Fig. 28. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaragod, August 25, 1974 (from Anon., 1976).
Fig. 29. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l) off Kasaraqod, November 6, 1974 (from Anon., 1976).
Fig. 30. Vertical Sections of (a) Temperature ($^\circ$C) and (b) $\sigma_t$ (g/l) off Kasargod, December 11, 1974 (from Anon., 1976).
Unlike the southerly flow during the previous month, the northerly current is wide and deep reaching. The surface temperature is above 28°C and the mixed layer is deeper than 100 m. There is a general decrease in density and an increase in temperature at all depths down to 300 m.

2.5. Vertical sections of temperature off Karwar:

Oceanographic data collected from October 1971 to December 1972 during the Pelagic Fishery Survey are used for the present study (Figs. 31-33). The figures are reproduced from Anon. (1973). Most of the investigations are confined to the continental shelf and the outermost station is about 50 miles offshore. The distance between two stations is about 10 miles. Only vertical sections of temperature are presented.

2.5.1. October

The thermocline is found almost at the surface in the continental shelf region (Fig. 31a). The surface temperature is about 25°C near the coast and it increases to 27°C at a distance of 10 miles offshore. The surface current is weak southerly between stations I and IV, but turns to strong southerly further offshore. The isotherms slope down towards the coast below 50 m, indicating a northerly current.
Fig. 31. Vertical Sections of Temperature (°C) off Karwar
(a) October (b) November and (c) January
(from Anon., 1973)
2.5.2. November

The surface temperature increases to above 28°C (Fig. 31b). There is a considerable increase in temperature at all depths between October and November. The 22°C isotherm which is observed at about 20 m in October is displaced to about 110 m in a span of 49 days. Except in the upper 30 m, the isotherms show a downward tilt towards the coast.

2.5.3. January

The temperature in the surface layers ranges from 27-28°C (Fig. 31c). Between stations I and IV the isotherms slope down towards the coast indicating a northerly flow, but further offshore the flow is southerly.

2.5.4. March

The mixed layer deepens from January to March to below 100 m (Fig. 32a). The surface temperature is above 30°C near the coast, but decreases to 29°C in the offshore.

2.5.5. April

The isotherms slope up towards the coast indicating a southerly current (Fig. 32b). The surface temperature continues to be above 29°C, but the depth of mixed layer decreases to about 70 m. There is a general
Fig. 32. Vertical Sections of Temperature (°C) off Karwar
(a) March (b) April and (c) July (from Anon., 1973).
decrease of temperature between 70 and 100 m from March to April, though no significant changes are observed in the surface layers.

2.5.6. July

The thermocline is observed just below the surface in the nearshore regions (Fig.32c). The surface temperature is about 27°C near the coast and increases offshore. The isotherms slope up towards the coast indicating a southerly current in the upper 100 m. Considerable upward displacement of isotherms are evident from April to July.

2.5.7. August

By the end of August further decrease in temperature above 100 m is noticed except at the surface compared to July (Fig.33a). The surface flow continues to be southerly and there is slight indications of a subsurface countercurrent below 60 m.

2.5.8. October

The surface temperature is above 29°C near the coast and a slight increase in temperature at all depths is evident from August to October (Fig.33b). At the edge of the continental shelf a strong thermocline is noted between 30 and 50 m.
Fig. 33. Vertical Sections of Temperature (°C) off Harmer  
(a) August (b) October and (c) December  
(from Anon., 1973)
2.5.9. December

The temperature increases considerably in the upper 100 m from October to December (Fig.33c). The surface temperature is above 29°C. At the edge of the continental shelf the depth of mixed layer is about 80 m.

2.6. Vertical sections of temperature off Ratnagiri:

The vertical temperature sections off Ratnagiri are reproduced from Anon. (1973). The observations were made in February and August (Fig.34).

2.6.1. February

During this month the surface temperatures are above 27°C in the nearshore regions and the depth of mixed layer is about 90 m (Fig.34a). The flow between the the Angria bank and the coast is not clear but further offshore the orientation of isotherms indicates a northerly flow.

2.6.2. August

The conditions during this month show some significant differences from those in the southern regions (Fig.34b). The surface temperature is well above 28°C in nearshore and offshore regions. The depth of thermocline is about 40 m in nearshore regions and it increases towards offshore. The upsloping of isotherms towards the coast
Fig. 34. Vertical Sections of Temperature (°C) off Ratnagiri
(a) February and (b) August (from Anon., 1973).
suggests a southerly current. Upward displacement of isotherms are evident during the period February to August. The 23°C isotherm which is observed below 100 m in February is found at about 50 m in August in the nearshore regions.

Temperature and density fields off the east coast of India

Oceanographic investigations are not continuous and they are scarce off the east coast compared to those off the west coast of India. The available data are mainly confined to two places - off Waltair (17°44'N) and off Madras (13°08'N) (Figs.35-43). Further, the observations were conducted in different years, which is a limitation for a detailed discussion and to draw inferences.

2.7. Vertical sections of temperature and \( \sigma_t \) off Waltair:

The sections off Waltair were covered during January, March, April, July and October. For March and October only vertical sections of \( \sigma_t \) are presented (from LaFond and LaFond, 1968).

2.7.1. January

The observations off Waltair were taken in late January (Fig.35). The surface temperature is slightly
Fig. 36. Vertical Section of $\sigma_t$ (g/l) off Waltair for March (from LaFond and LaFond, 1968).
FIG. 37. VERTICAL SECTIONS OF (a) TEMPERATURE (°C) AND (b) $\sigma_z$ (kg/m$^3$)
above 25°C and the mixed layer is about 75 m deep. A temperature inversion is observed near the coast between 20 and 60 m. The isotherms and isopycnals below 50 m run nearly parallel to the surface. Very near the coast, the surface density is very low.

2.7.2. March

The figure is reproduced from LaFond and LaFond (1968). The density field shows clear upsloping towards the coast indicating a fairly strong northerly flow (Fig. 36). There is an increase in density at all depths above 100 m from January to March and this increase is more conspicuous in nearshore regions. The 22.0 g/l isopycnal outcrops into the naviface. At about 30 miles from the coast the increase in density from January to March is much less.

2.7.3. April

The surface temperature near the coast has increased to 28°C and still higher values are observed further offshore (Fig. 37). The upsloping of isotherms and isopycnals continues in April also. The depth of mixed layer is about 50 m in nearshore regions and it increases offshore. There is a slight decrease in density at all depths between March and April.
Fig. 38. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g) off Waltair for July (from Murthy and Varadachari, 1968)
Fig. 39. Vertical Section of $c_t$ (g/l) off Waltair for October (from LaFond and LaFond, 1968).
2.7.4. July

The figures are reproduced from Murthy and Varadachari (1968). In early July the surface temperature is about 26°C near the coast and increases to about 28°C at 10 miles offshore (Fig. 38). The 22.0 g/l isopycnal outcrops into the naviface. The isotherms and isopycnals are pushed up from April to July. The upwelling of isotherms and isopycnals towards the coast suggests a northerly current.

2.7.5. October

The figure is reproduced from LaFond and LaFond (1968). The isopycnals slope down towards the coast indicating a southerly current (Fig. 39). The density of the surface layers is low especially in the nearshore regions. Considerable downward movement of isopycnals is evident during the period July to October.

2.8. Seasonal variation of temperature and $\sigma_t$ at different depths off Waltair

The curves used here are reproduced from Varadachari (1963) (Fig. 40). The surface temperature is highest during September-October and again in April-May. The lowest surface temperatures are observed during December-January. At 125 m, the temperature begins to decrease from December and reaches a minimum in March.
Fig. 40. Seasonal variations of (a) Temperature (°F) and (b) $\sigma_t$ (g/l) at different depths of Waltair (from Varadachari, 1963).
But at 75 and 50 m the variation of temperature is not continuous till February. The temperature at these depths decreases sharply from February to March. After March, the temperature increases till May. For June, July and August no data is available, but during September the temperature shows a secondary minimum at all depths except at the surface. This indicates that the temperature decreases at subsurface depths sometime during June to August. From September onwards, the temperature increases between 25 and 125 m and reaches a peak in November. During October - February the temperature in the upper 50 m exceeds that at the surface, while the temperature at 75 m exceeds that at the surface between October and November.

The density field also shows large seasonal variation and it is maximum at the surface. The surface density is the least in September-October and maximum during January-August. The density variation at subsurface layers is less and it mainly depends on the temperature structure unlike in the surface layer. The density at 80 m depth is high in March and again in September, while it is the least in November, and again in April-May.

2.9. Vertical sections of temperature and \( \sigma_t \) off Madras:

The sections off Madras were covered during January, April, May and June. Due to the unavailability of data for
the northeast monsoon, it could not be presented.

2.9.1. January

The surface temperature is about $26^\circ$C which is higher than that off Waltair for this month (Fig.41). The depth of mixed layer is about 85 m in nearshore regions. The isotherms and isopycnals show upsloping towards the coast in the nearshore regions indicating a weak northerly flow, but further offshore the flow is southerly.

2.9.2. April

The isotherms and isopycnals slope up towards the coast indicating a northerly current. The surface temperature is fairly high - about $28^\circ$C in nearshore and increases offshore (Fig.42). Near the coast, the thermocline is observed below 50 m. The density increases at all depths from January to April and this increase is more prominent in the nearshore regions.

2.9.3. May

The surface temperature is above $28^\circ$C in nearshore regions and increases to $29^\circ$C at about 25 km from the coast (Fig.43). The isotherms and isopycnals slope up towards the coast indicating a northerly current. The mixed layer is about 50 m deep near the coast, but at about 50 km from the
Fig. 46 Vertical Sections of (a) Temperature (°C) and (b) σθ (g/cm²)
off Madras, January 31-February 1, 1965.
Fig. 4.2. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l)
off Madras, April 7-8, 1965.
Fig. 3. Vertical Sections of (a) Temperature (°C) and (b) $K$ (W/m²K) off Madeira, May 1963.
Fig. 44. Vertical Sections of (a) Temperature (°C) and (b) $\sigma_t$ (g/l)

off Madras, June 20-23, 1963
coast the depth of mixed layer increases to about 100 m. A slight decrease of density is observed at all depths except in the surface layers from April to May. There are no indications of a subsurface countercurrent down to a depth of 250 m. It is interesting to note that the upsloping of isopycnals is marked only up to a distance of about 40 km from the coast.

2.9.4. June

The upsloping of isotherms and isopycnals continues in this month also (Fig. 44). The density field does not show much variation from that of May. The surface temperature is about 28°C near the coast and slightly increases offshore.