HYDROGRAPHICAL FEATURES OF THE INNER SHELF WATERS ALONG THE CENTRAL WEST COAST OF INDIA DURING WINTER, SPRING AND SUMMER

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ABSTRACT

Physical oceanographic data collected on board *Arjun Prasad* during the monthly cruises from January to April, 1972 in the sea extending upto 15 miles offshore along the central west coast (Vengurla to Karwar) have been analysed and the results are discussed. In winter, the waters were well mixed and homogeneous. From March onwards they exhibited significant temperature and density gradients. Incursion of relatively saline and dense subsurface waters along the inner shelf due to upwelling was encountered in March and April off Karwar and in April off Cape Ramas and Aguada. Surface currents in the nearshore regions showed a complex pattern while those in the offshore regions of the southern part (off Cape Ramas and Karwar) could be related to the seasonal drifts.

INTRODUCTION

The sea off the west coast of India is an important region of the world oceans known for rich fisheries and some fascinating physical phenomena like upwelling and sinking. Even though the occurrence of upwelling in the shelf waters off the west coast of India is well established, its mechanism and its seasonal and year to year variations are not fully understood. A better knowledge of these phenomena and the associated changes in the hydrographical conditions will greatly help in planning successful fishing operations. Even though many works were reported by several authors on the hydrographical features in the shelf waters of the west coast of India, they mostly deal with general conditions for specific seasons and regions. After reviewing the available literature, it is felt that an intensive study of the region incorporating investigations on the month to month variations in the hydrographic parameters and currents in the shelf waters is essential to achieve a better understanding of these physical processes. The studies carried out on these lines in the inner shelf waters off the central part of west coast of India during the premonsoon period of 1972 are reported in this paper. The works of Ramamirtham and Patel (1965), Rao *et al.* (1969), Annigeri (1972) and Varadachari *et al.* (1974) deserve special mention among the earlier investigations concerning the hydrographical features of the area investigated and the period covered under the studies reported here.

COLLECTION AND TREATMENT OF DATA

In the sea along the central west coast extending from Vengurla in the north to Karwar in the south, eight cruises were carried out on board a chartered vessel *Arjun Prasad* during the period January to April 1972. In these cruises four sections, located perpendicular to the coast off Vengurla (Section 1), Aguada (Section 2), Cape Ramas (Section 3) and Karwar (Section 4) each comprising of four stations situated at distances of 1.6, 4.8, 12.8 and 24 km. from the coast were worked out every month. The details of the cruises viz., the period and the area covered are given in Table 1. The locations of stations and sections are shown in Fig. 1.

At each station, the vessel was anchored, bathythermograph was operated, the water samples were collected at 5 to 10 m depth intervals from surface to bottom using Nansen bottles fitted with deep sea reversing thermometers and the water temperatures noted. The surface currents (about 2.5 metres below the sea surface) were measured using an Ekman type currentmeter. Secchi Disc was operated to assess the water transparency. Data on some meteorological parameters such as winds etc. were also recorded at each station.

The temperature data were processed by applying necessary thermometric corrections to the readings of the reversing thermometers and cross checking the values with the BT records. Inductive Salinometer and Knudsen's method were used to estimate salinity of the water samples. The density (σ_t) values were evaluated from the temperature and salinity data using the Tables for sea water density (U. S. Navy Hydrographic Office, 1952). Vertical profiles of temperature, salinity and density (σ_t) along the four sections were prepared for each month and shown in Figs. 2 to 5. While analysing the sections, the isotherms were drawn at intervals of 0.5°C, the isohalines at intervals of 0.2‰ and the isopycnals (σ_t lines) at intervals of 0.2.

Table I. *Details Of Cruises*

Cruise	Period	Sections Covered
AP-6	24–25 January 1972	3 and 4
AP-7	29–30 January 1972	2 and 1
AP-13	22–23 February 1972	2 and 1
AP-18	7–8 March 1972	3 and 4
AP-23	20–21 March 1972	2 and 1
AP-25	23–24 March 1972	3 and 4
AP-33	25–26 April 1972	2 and 1
AP-34	28–29 April 1972	3 and 4

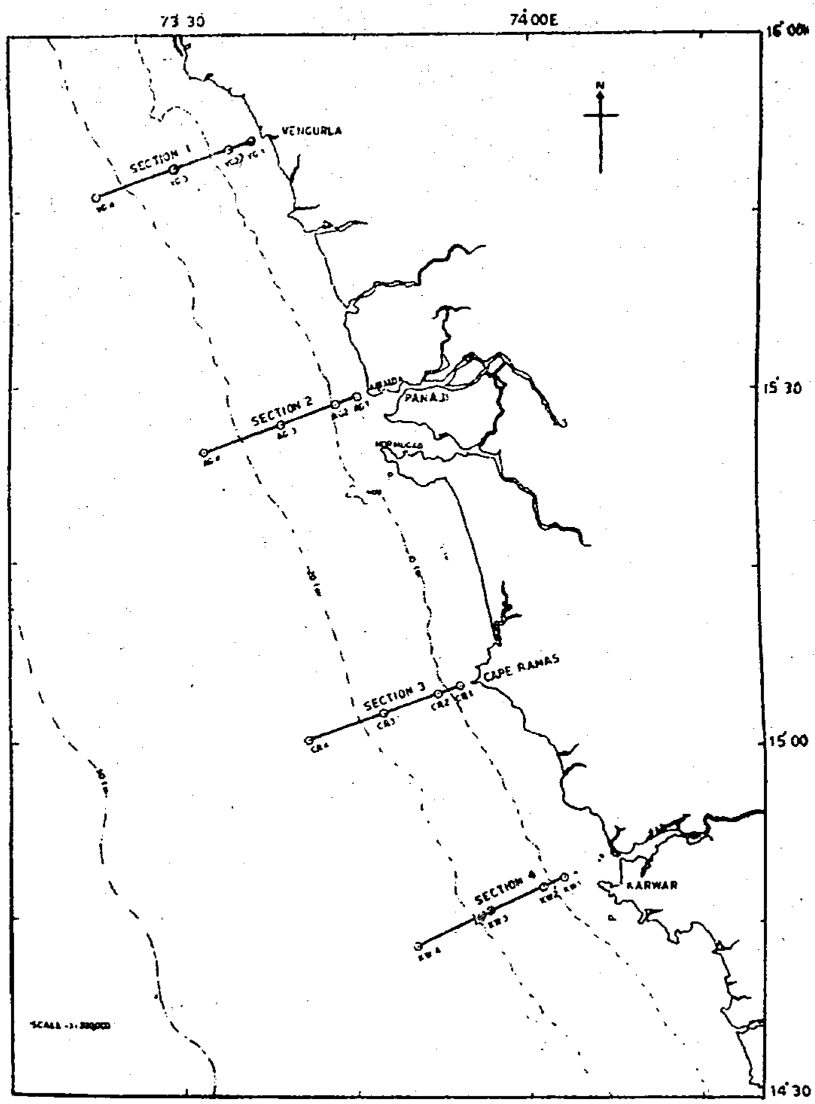

Fig. 1 Chart showing the location of stations and sections. (1 fathom = 1.8288m)

RESULTS AND DISCUSSION

Temperature, Salinity and Density : January : Fig. 2 shows the vertical distribution of temperature, salinity and σ_t along the four sections in January, which can be taken as a representative month for winter. During this month, the thermal gradients were weak and the waters were well mixed in all the sections. The water temperature slightly increased seaward from about 27°C in the nearshore waters to about 28°C in the offshore waters. This general isothermal feature appeared to have resulted from the influence of winter cooling of the adjoining coastal areas on the

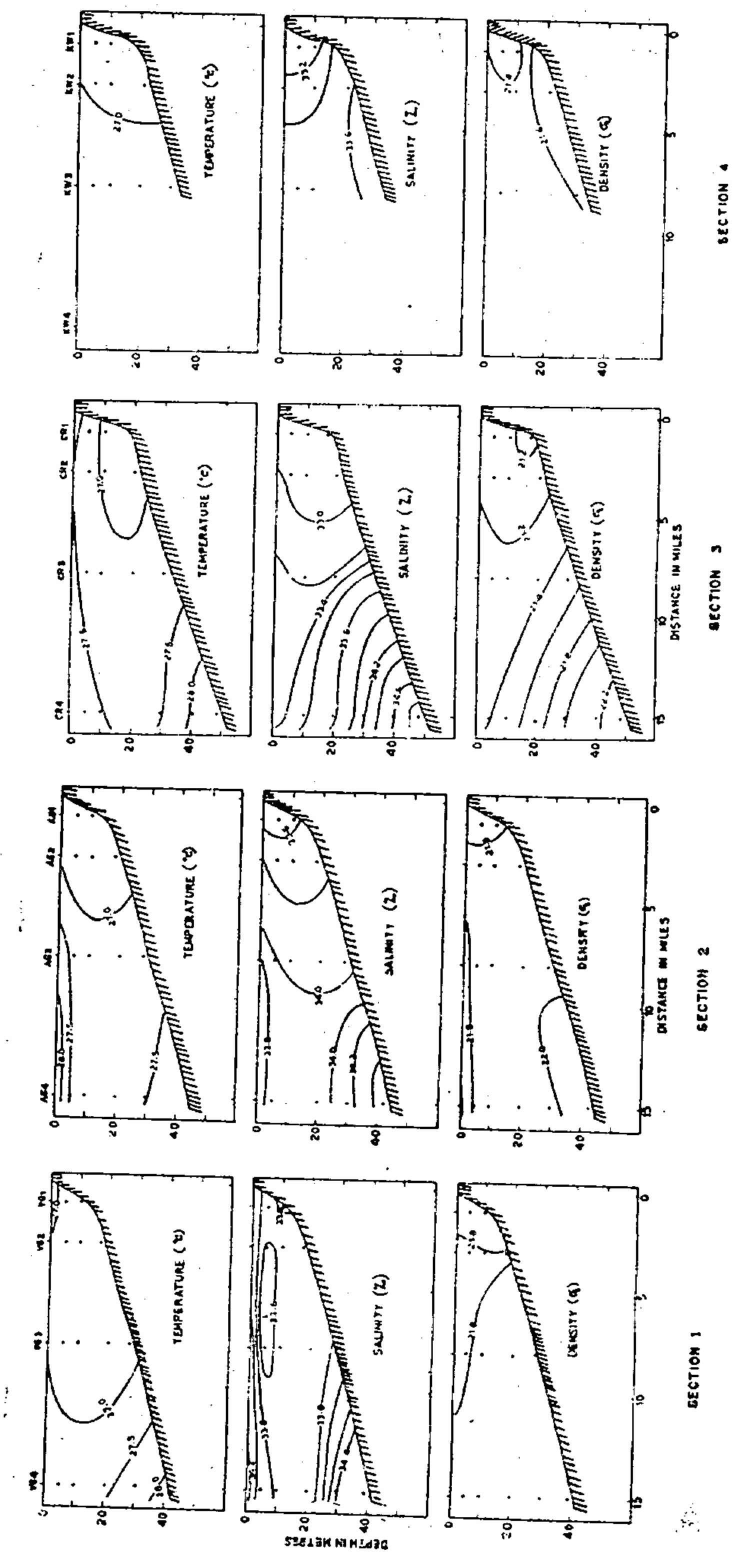

Fig. 2 Vertical distribution of temperature, salinity and density (σ_t) in January.

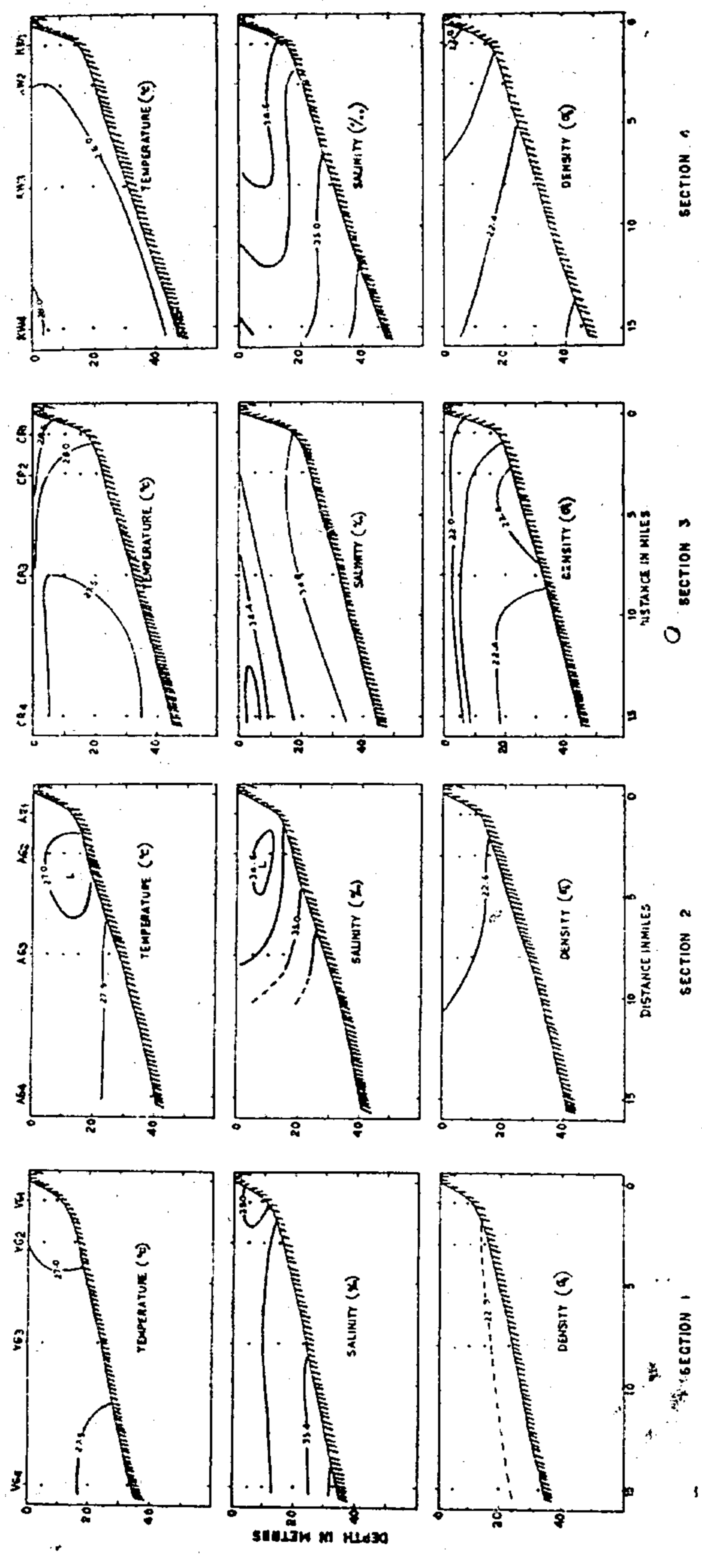

Fig. 3 Vertical distribution of temperature, salinity and density (σ_t) during Feb–March.

shore waters and the thorough mixing of these coastal waters by strong land and sea breezes prevailing during this period.

The salinity, in general, was found to increase in the offshore direction and with depth, the variation being from less than 33.6‰ in the nearshore waters to more than 34.4‰ in the deeper waters of the offshore region. A layer of relatively low salinity water ($S < 33.8‰$) observed in the upper 25 metres along Section 1 (off Vengurla) suggest northward movement of waters from Mandovi and Zuari estuaries. In the sections off Aguada, Cape Ramas and Karwar (Sections 2, 3 and 4 respectively), the influence of estuarine waters is clearly seen in the salinity structures. Off Cape Ramas (along Section 3), relatively strong salinity gradients were encountered beyond 12.8 km. from the coast.

Along Sections 1, 2 and 4, the density (σ_t) profiles show nearly homogeneous waters. It was interesting to note that the density (σ_t) structure along Section 3 (off Cape Ramas) is indicative of sinking. The density profile for the Section 1 (off Vengurla) also suggest some sinking. This feature is absent in the sections off Aguada and Karwar perhaps due to the influence of estuaries.

February-March : February can be considered as the transition period from winter to spring. The vertical profiles of the different parametres for this period are shown in Fig. 3. Along Sections 1, 2 and 4, the waters were nearly isothermal and well mixed. The decrease in temperature in the offshore direction in Section 3 (off Cape Ramas) and the presence of slightly warmer water (~ 28°C) compared to January in Section 4 (off Karwar) indicate that the winter cooling prevailing in the previous month has stopped and the seasonal heating has started.

Along Sections 2 and 3, the salinity increased in the offshore direction and with depth. A gradual increase in salinity with depth was observed along Section 1. Off Cape Ramas (along Section 3), a tongue of relatively low salinity water ($S < 34.4‰$) was observed in the upper 10 metres and the isohalines, in general, followed the slope of the bottom configuration in this region. The density structure revealed the presence of highly homogeneous waters along Sections 1 and 2, and stratified waters along Sections 3 and 4.

March : Fig. 4 shows the distribution of various parameters in March, representing the conditions in spring.

Seasonal heating of the surface layer could be seen from a significant rise in the temperature of the waters in the upper 20 metres in all the sections. There was no significant variation in temperature in the offshore direction and the isotherms, generally, ran parallel to the sea surface. Strong thermal gradients (of the order of 1°C/5 m) found in the upper 5 metres along Section 2 off Aguada) perhaps indicate intense heating at the sea surface, characteristic of the spring season.

Along sections 1, 2 and 3 the waters were nearly isohaline ($S = 34.4$-$34.6‰$) in the upper 20 metres. In Sections 2, 3 and 4 below 20 m depth, the salinity gradient was relatively more than that in the surface waters and showed an

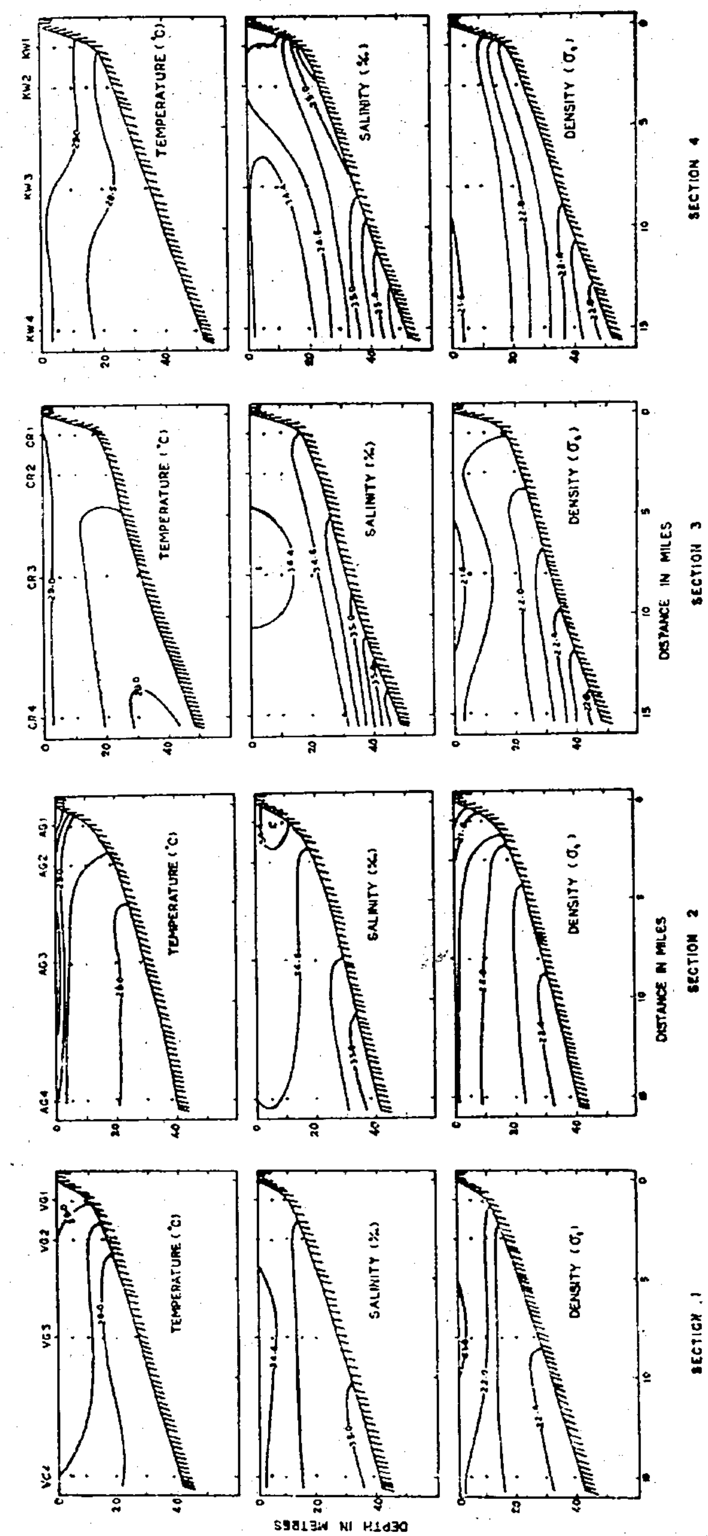

Fig. 4 Vertical distribution of temperature, salinity and denstity (σ_t) in March.

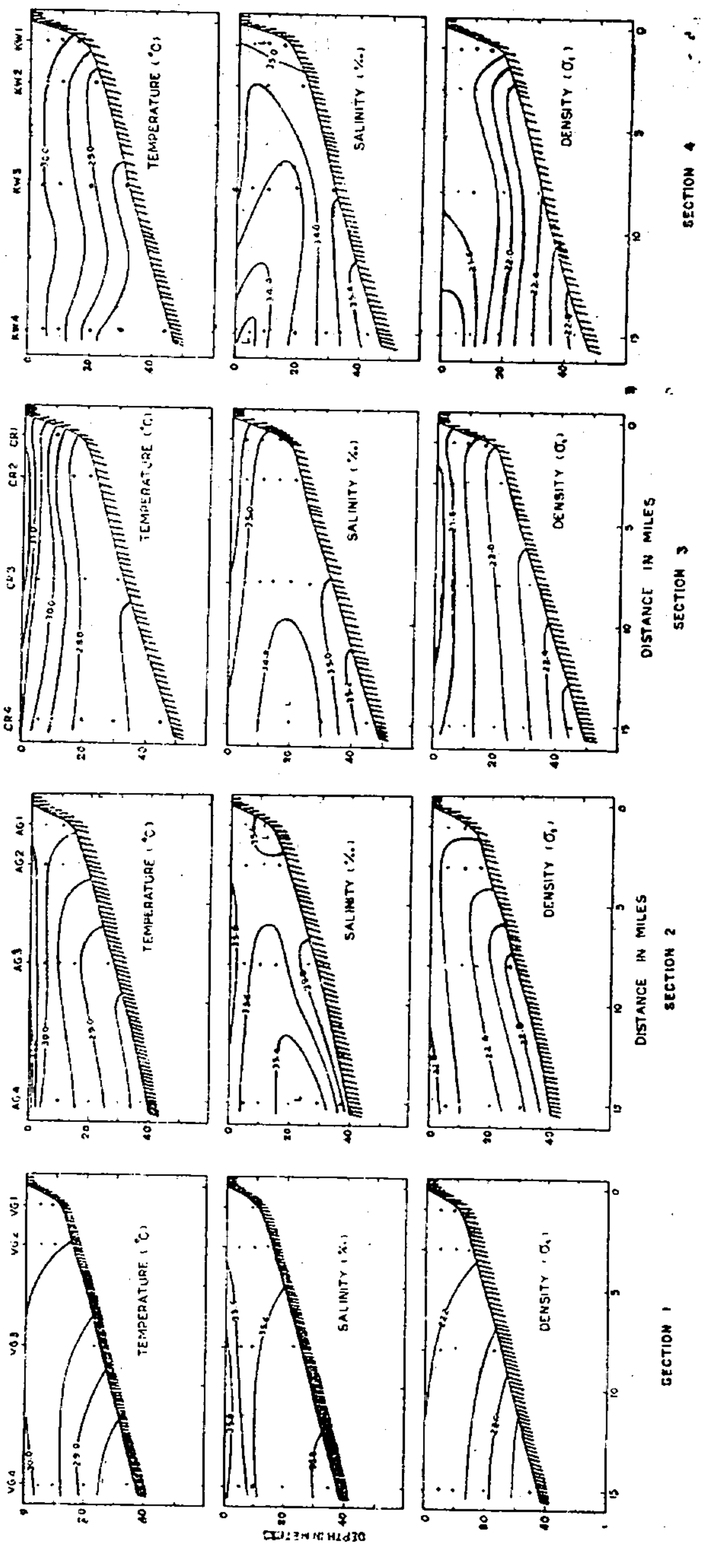

Fig. 5 Vertical distribution of temperature, salinity and density (σ_t) in April.

increase in the southerly direction. The upward tilting of isohalines in the nearshore waters along Section 4 (off Karwar) could be clearly seen. This feature in association with the slight upward tilt of isopycnals suggested the upward movement of sub-surface waters along the inner shelf. It is interesting to note that the same feature was reported by Varadachari *et al.* (1974) for the Section off Karwar, in their study based on the data collected on board INS *Kistna* in the last week of March 1965 under the IIOE Programme.

April : April may be taken as the typical month for discussing the summer conditions. The veritical profiles of various parameters for this month are presented in Fig. 5.

In all sections, a further increase in the temperature of the waters was observed during this month. The temperature was generally above 30°C in the nearshore waters and in the upper 5 metres of the offshore waters, where it decreased gradually with depth. The temperature gradient in the upper 20 metres was found to increase southwards from Section 1 to Section 3 (off Cape Ramas) where high vertical temperature gradients (of the order of 3°C/20 m) were encountered. But further south (along Section 4 off Karwar), the vertical temperature gradient was found to be slightly less. The general tilting up of the isotherms, isohalines and isopycnals along the inner shelf in Sections 2, 3 and 4 indicates upward movement of subsurface waters along the inner shelf. The isolines further suggest that the relatively dense subsurface waters associated with upwelling has moved up to about 20 m depth along the inner shelf.

The salinity profiles along Sections 2, 3 and 4 show complex pattern resulting from the admixture of relatively low salinity waters from the estuaries and subsurface waters of higher salinity moving upward along the inner shelf.

Water Transparency : The data on maximum depth of visibility as obtained by Secchi disc and the approximate values of extinction coefficient (k) calculated therefrom using the relation, $k = 1.7/D$, where D is the Secchi disc reading in metres (Poole and Atkins, 1929) are shown in Table II. In January, the transparency of the waters was very low (low Secchi disc readings) at the nearshore stations, while the offshore stations recorded fairly high Secchi disc readings. The same feature continued in February and March except for a steady increase in the transparency of the waters in general. There was a slight decrease in the transparency of waters, in general, from March to April.

Surface Currents: The data on surface currents for different months are presented in Table III. The currents in the nearshore regions exhibited the influence of tides. This tidal influence was found to be considerable in the nearshore regions off Aguada and Karwar due to their proximity to the river mouths. During January and February, the currents in the offshore region showed the seasonal northerly drift (Varadachari and Sharma, 1967) while those in the inshore waters suggested a general southerly flow with some modifications caused by tidal influence near the opening of Mandovi – Zuari estuarine system, the group of islands off the Mormugao Headland and the Cape Ramas Headland. During March and April, the general flow in

TABLE II. *Transparency and Extinction Coefficient of Waters off the Central West Coast of India*

Station No.	January		February–March		March		April	
	Max. depth of visibility	Approx. extinction coeft. k	Max. depth of visibility	Approx. extinction coeft. k	Max. depth of visibility	Approx. extinction coeft. k	Max. depth of visibility	Approx. extinction coeft. k
VG 1	—	—	—	—	3.0	0.57	6.0	0.28
VG 2	2.5	0.68	1.8	0.95	3.5	0.49	8.0	0.21
VG 3	3.4	0.50	7.6	0.22	15.0	0.11	10.0	0.17
VG 4	17.0	0.10	14.0	0.12	20.0	0.09	15.0	0.11
AG 1	3.4	0.50	1.5	1.13	2.2	0.77	3.0	0.57
AG 2	3.0	0.57	1.8	0.95	16.0	0.11	9.0	0.19
AG 3	4.5	0.38	4.0	0.43	18.0	0.10	12.0	0.14
AG 4	16.0	0.11	10.0	0.17	20.0	0.09	17.0	0.10
CR 1	2.0	0.85	2.8	0.61	13.0	0.13	2.0	0.85
CR 2	3.0	0.57	3.4	0.50	16.0	0.11	3.0	0.57
CR 3	4.0	0.43	23.0	0.07	18.0	0.09	21.0	0.08
CR 4	—	—	25.0	0.07	24.0	0.07	26.0	0.07
KW 1	—	—	3.2	0.53	8.0	0.21	3.0	0.57
KW 2	—	—	3.8	0.45	16.0	0.11	8.0	0.21
KW 3	—	—	21.8	0.08	25.0	0.07	20.0	0.09
KW 4	—	—	23.0	0.07	32.0	0.05	29.0	0.06

TABLE III *Surface Currents off the Central West Coast of India*

Station No.	January		February-March		March		April	
	Current Dir.	Speed (cm/sec)	Current Dir.	Speed (cm/sec)	Current Dir.	Speed (cm/sec)	Current Dir.	Speed (cm/sec)
VG 1	N	3.6	SW	3.4	NW	2.6	W	17.9
VG 2	NNE	4.2	S	8.2	W	4.7	WNW	19.1
VG 3	NNW	3.2	SW	8.4	WNW	8.7	WNW	27.3
VG 4	WNW	8.8	N	9.7	N	14.5	NW	25.5
AG 1	S	22.1	SW	5.7	–	–	NW	10.9
AG 2	SSW	3.3	SSE	15.3	N	13.3	NNW	13.7
AG 3	SE	8.0	S	13.9	N	3.2	N	16.7
AG 4	WNW	10.8	–	–	W	2.6	SE	21.4
CR 1	–	–	SW	20.2	–	–	WNW	9.7
CR 2	–	–	S	12.1	WSW	12.6	W	11.5
CR 3	N	2.7	SW	18.1	WSW	8.5	WSW	18.2
CR 4	WNW	10.0	WSW	15.2	WSW	10.9	W	10.9
KW 1	–	–	ESE	9.3	W	8.5	NE	16.1
KW 2	E	20.3	ESE	11.9	–	–	–	–
KW 3	E	17.8	–	–	SW	21.4	W	13.0
KW 4	–	–	WSW	6.8	SW	13.2	WSW	20.8

the northern part of the region under study was mostly northward with relatively stronger currents (speeds upto 27 cm/sec) off Vengurla. However, in the southern part (off Cape Ramas and Karwar), the flow was mostly offshore, which perhaps formed part of the circulation with northerly component in the inshore waters and seasonal southerly drift (Varadachari and Sharma, 1967) in the offshore waters.

CONCLUSIONS

The temperature of the surface waters increased gradually from 27–28°C in January to 30–31.5°C in April. The waters were nearly isothermal, well mixed and homogeneous in winter. From March onwards, significant increase in temperature and density gradients was found. The salinity distribution in January revealed the influence of waters from the estuaries joining the sea and their movement in the inner shelf region. The density structure off Cape Ramas and Vengurla suggested sinking. Incursion of relatively saline and dense subsurface waters along the inner shelf due to upwelling was found in March and April off Karwar and in April off Cape Ramas and Aguada suggesting that upwelling started in the southern part earlier. These subsurface waters seem to have moved up to about 20 m depth along the inner shelf and upwelling does not seem to have reached the surface by April. The transparency of waters, in general, increased in the offshore direction and from winter to spring. Currents in the nearshore regions, in general, showed a complex pattern resulting from the tidal influence, which was significant near the openings of estuaries and the obstructions caused by the islands off Mormugao Head and the Cape Ramas Headland. During January and February, the currents in the offshore region showed the seasonal northerly drift. During April, relatively strong northward currents with speeds upto 27 cm/sec were observed off Vengurla and the flow was mostly offshore off Cape Ramas and Karwar.

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