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UPSLOPING OF ISOTHERMS ON THE CONTINENTAL SHELF OFF GOA AND BOMBAY IN JUNE 1967*

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ABSTRACT

Bathythermograph sections made in June 1967 in the northeastern Arabian Sea on and near the continental shelf west of Goa, and west and northwest of Bombay, showed a rise of isotherms below the mixed layer, over the levels observed in May in other years. This was especially so in the southern and central part of the area; near Bombay, 35 km from shore, temperatures of 26°C were met at 40 m. However, the very shallow depth reached regularly by much cooler water from July through November had not nearly been attained. It is concluded that seasonal upsloping begins off Goa always before June. It is argued that it is likely to be the case off Bombay too, but the few available observations do not support this. Marked raise of isopycnals towards the coast before the arrival of the southwest monsoon can be expected off Veraval.

A trough of the thermocline, approximately 20 m deep in 1967, is a regular feature during the pre-monsoonal months on the outer shelf west and northwest of Bombay.

INTRODUCTION

DURING her maiden cruise around the world, the USC & GSS *OCEANOGRAPHER* spent June 1967 in the northeastern Arabian Sea. The ship approached the continental shelf near Goa, on the way to Bombay, then ran four sections across the shelf west and northwest of Bombay, and left the area passing Goa again.

June is the usual time of the arrival of the rain of the southwest monsoon in the area. In 1968, I had surmised that June would also be the usual time of first upsloping of cool subsurface water onto the shelf where it is present through November or even mid-December. Because previously almost no subsurface observations had been available from the shelf for June, the *OCEANOGRAPHER* sections were a welcome opportunity to explore the upsloping which is of theoretical interest as well as has practical implications.

It is a pleasure to acknowledge the co-operation by the oceanographic staff of the former U.S. Coast and Geodetic Survey of the Environmental Science Services Administration (now in the National Oceanic and Atmospheric Administration), especially Dr. H. B. Stewart, who arranged on short notice for the desired observations. I am also much obliged to the scientific party chiefs, Drs. F. Ostapoff and R. E. Burns, and Capt. G. Haraden. Mr. C. V. Mahnken digitized many observations provisionally on board ship thus aiding initial evaluation of the results. The U.S. National Oceanographic Data Center made a special effort for early processing of the mechanical bathythermograph records. The Deputy Director-General of

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Observatories (Forecasting) of the Indian Meteorological Department provided data of surface observatories and ships. Finally it must be pointed out that the invitation to contribute to the present symposium had a beneficial effect on the final completion of the study. The Research Fund of the Graduate School of the University of Washington supported partially the preparation of the manuscript.

Material and Methods

The core of the material are wind data and bathythermograph (BT) observations made in 1967 by the *OCEANOGRAPHER* from 6 June morning to 8 June morning, Indian Standard Time (IST) on stations 99 to 135 inbound for Bombay, from 13 June afternoon to 21 June evening on stations 1 to 67, Bombay to Bombay, and from 28 June afternoon to 29 June midnight on stations 1 to 11, southbound from Bombay (Fig. 1).

Wind data : For the period 10 May to 25 June, observations of surface winds were available for 17:30 IST for Ratnagiri, Bombay and Veraval (U.S. Department of Commerce, 1967). For the period 5 June to 30 June additional data from 08:30 and 17:30 IST for 18 coastal stations, including the named three, between Goa and the border between India and Pakistan were obtained from the Indian Meteorological Department. From the same source some ship observations were also at hand. Wind observations by the *OCEANOGRAPHER* for the positions of each BT cast were taken from the BT log sheets. Finally, use could be made of a typewritten report by the meteorologist of the *OCEANOGRAPHER*, Mr. C.L. Campbell, who had evaluated synoptic weather maps, radiosonde data, and satellite photographs.

Wind vectors for the evening observations from Ratnagiri and Bombay were plotted for the seven one-week periods preceding 30 June 1970 because the calculations by Schmitz (1967) and Lighthill (1969) suggest that three to four weeks may be required before winds and thermocline depths or currents are in equilibrium in this region. The resulting average directions and speeds (Fig. 1) allow the qualitative evaluation of the wind conditions on the coast for three to four weeks prior to the observations by the ship between Goa and Bombay, approximately on 7 and 29 June. The data from Veraval were treated in the same manner.

Mean wind vectors for the observations by the *OCEANOGRAPHER* were determined by grouping stations with similar wind speeds and weighting the data according to the time intervals they represented (see the different spacing of stations in Fig. 1). Some measurements came from positions not included in the map where the BT's failed to operate.

Water temperatures : Mechanical and expendable bathythermographs were employed as indicated in Fig. 1. Most of the former observations, all taken by the same instrument, were digitized for 5 m intervals by the National Oceanographic Data Center, Washington, D.C. For the remainder, records digitized provisionally on board ship were utilized. Temperatures for the casts made with the expendable BT's were read by the author from copies of the original analog records, usually neglecting the uppermost 1 or 2 meters.

Temperature corrections (TCS) for the mechanical BT were obtained as follows : If the surface records in the printouts by the Data Center did not deviate by more than 0.2°C from the values at 5 m, differences between the former and the bucket temperatures were calculated. In the three cases where the surface readings seemed erratic, the means of the values for 5 and 10 m were used. For these and 47 other observations, the standard deviation (SD) from the mean of the differences

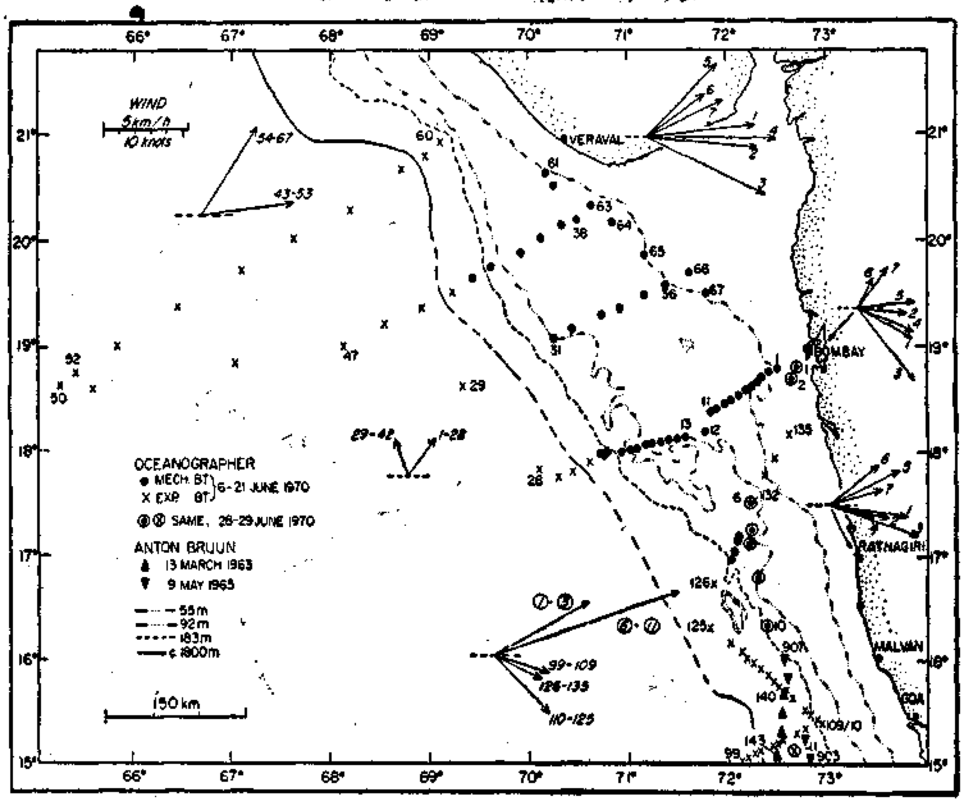

Fig. 1. Locations of the BT casts by *OCEANOGRAPHER*, 1967, and of selected casts by *ANTON BRUUN*, 1963. Numbers near station symbols are station numbers. A.B. station 905 is just south of Oc. Station 115. Isobaths from U.S. Naval Oceanographic Office charts No. 1589 (7th ed., revised 1965) and No. 1590 (10th ed., revised 1964). Vector means of wind speeds and directions (see also text) for stations by *OCEANOGRAPHER* as indicated ; for Ratnagiri, Bombay and Veraval for seven-day periods starting 12 May 1970.

between surface and bucket temperatures was computed on the advice of Mrs. M. K. Robinson (Scripps Institution of Oceanography). Those five differences which were larger than two SD's were then omitted and a new mean calculated. All remaining differences were within two SD's from the new mean (−0.6° ; SD: 0.25°) which was applied to the printout from the Data Center. The TCS for the 34 observations between stations 96 and 135 in early June from the expendable BT's were calculated in the same way. After rejecting two large differences, the mean was 0° (SD : 0.27°). The TCS for the 44 slides digitized on board ship was also computed ; the resulting corrected surface temperatures deviated on the average by 0.1°C from the corrected values for all slides digitized by the Data Center. This difference then was added to the TCS for the provisionally digitized slides that were needed as a supplement as mentioned.

Depths of isotherms were interpolated for records by the mechanical BT and directly read from the analog records for the measurements with expendable BT's. Temperature observations by other ships made in previous years were obtained from the National Oceanographic Data Center (*ANTON BRUUN*, bathythermograph; *COMDR. R. GIRAUD*, *REQUISITE*, *VITYAZ*, and *V. VOROBYEV*, reversing thermometers).

RESULTS

Wind observations: Before the arrival of the *OCEANOGRAPHER* in the northeastern Arabian Sea, evening winds at Ratnagiri and Bombay came quite steadily from westnorthwest to northwest (Fig. 1). This holds largely also for the other coastal stations between Goa and Bombay for the period in early June when data were available. However, the morning winds at all these observatories were variable in directions and speeds, often with calms. At Veraval during May and early June, the winds were more westerly than at Ratnagiri and Bombay, and the average speeds were up to twice as high (Fig. 1). Through 10 June, winds similar in directions and strength prevailed at all stations west of 71°E. At these higher wind speeds, the influence of the land and sea breezes did not upset the general flow of the air. Some reports by ships near the coast, immediately north of the area shown in Fig. 1, are similar to the measurements by the shore stations.

The winds encountered by the *OCEANOGRAPHER* on the inbound journey to Bombay were very steady from the northwest. A crude measure of the uniformity in speed may be provided by the standard deviations from the arithmetic means of the raw data which are between one-fifth and one-third of the means, as is true also for the observations on the four sections west and northwest of Bombay in mid-June.

According to the report by Mr. C. L. Campbell, the rains of the southwest monsoon began at sea on 16 June (station 33); the ship encountered heavy rain again the next day (station 44). Whereas on 16 June the monsoon had developed along the entire Indian coast to a point just north of Bombay, it had spread on 17 June to about 550 km north of the city. By 19 June the monsoon had declined along the southwest coast of India.

At sea, the arrival of the rain resulted in roughly a doubling of wind speeds but not in large changes in directions after variable initial winds on the first day (Fig. 1). At Ratnagiri, Bombay and Veraval, the arrival of the monsoon affected primarily the wind direction which became more southwesterly; winds of 15 to 20 knots were observed only on stations near Goa, for a few days after the beginning of the monsoon. The wind speeds at Veraval and the locations west of 71°E were even lower in the latter two-thirds of June than in May and the first third of June. In the very last days of June, southwesterly to westerly strong winds were measured from Bombay southward as is also apparent from the data collected by the *OCEANOGRAPHER* (Fig. 1) which at the latitude of Ratnagiri encountered winds up to 30 knots. For 29 June, observations from four other ships are available from the latitude of Bombay and south showing likewise high wind speeds.

Water temperatures: In early June 1970 off Goa, the surface layer had temperatures of 29.5° to 30.5°C and reached to depths of 20 m to 35 m (average, about 25 m, Fig. 2). The 26° isotherm occurred between 42 m and 65 m (average approximately

55 m). The 20° isotherm was as shallow as 90 m. At the stations with less than 500 m bottom depth, very cool water was found at 80 to 100 m. Close to Bombay (stations 132 ff., <100 m depth, 7 June) the 25° and 26° isotherms rose steeply,

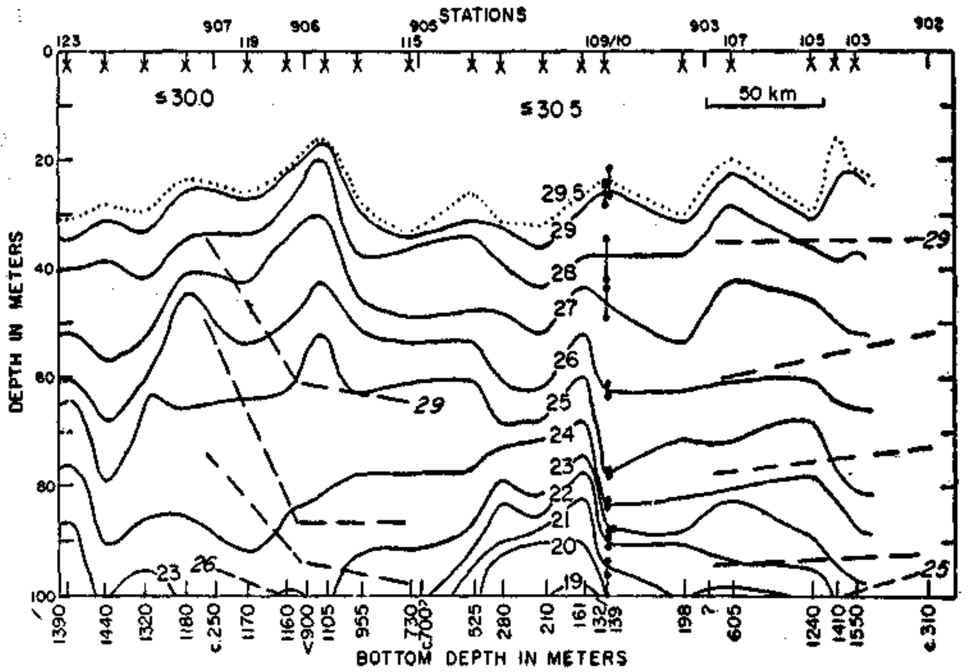

Fig. 2. Temperature (°C) section for stations 103 to 123 by *OCEANOGRAPHER*, 6 to 8 June 1970 (heavy lines); stations 902 to 907 by *ANTON BRUUN*, 9 May 1963 (broken). Station symbols with X : Expendable BT's ; otherwise mechanical BT. 30° isotherms omitted. At stations 109/110 isotherms are drawn through the mean depths of observations.

reaching 50 m and 40 m respectively. Approximately 35 km from the shore, water of 26.1° was observed at 30 m depth.

In mid-June, a representative temperature section across the continental shelf off Bombay (Fig. 3) showed water of 26.0° at 40 m depth at about the same distance from shore as found one week earlier nearby. Similar temperatures were measured at 55 m off the southern tip of Saurashtra (26.0° at stations 38 and 39; 26.5° at station 36 and at station 63, four and one-half days later) and at 50 m on the northernmost stations (25.4°, 23.8°, and 25.8° on stations 58, 59, and 60, respectively). The thermocline dipped markedly on the outer shelf in all sections except the northwesternmost one Fig. 4).* On the continental slope, cool water was found at relatively elevated levels except west of 67°E.

* The observations presented in Fig. 4 could also be interpreted such that the 50 m isobath, instead of ending at about 20°N, 70°E, connects through the area indicated by a query mark with the depression of the thermocline in the westernmost part of the studied region. Either interpretation of the observations is difficult to align with the general notion of a uniform broad clockwise current along the entire Indian Coast during this season.

Especially in the three northern sections not presented as figures, the 27°, 28°, and 29° isotherms were close together forming a 10 m to 15 m thick top layer of the thermocline. They were usually separated by a 10 m to 15 m wide depth interval

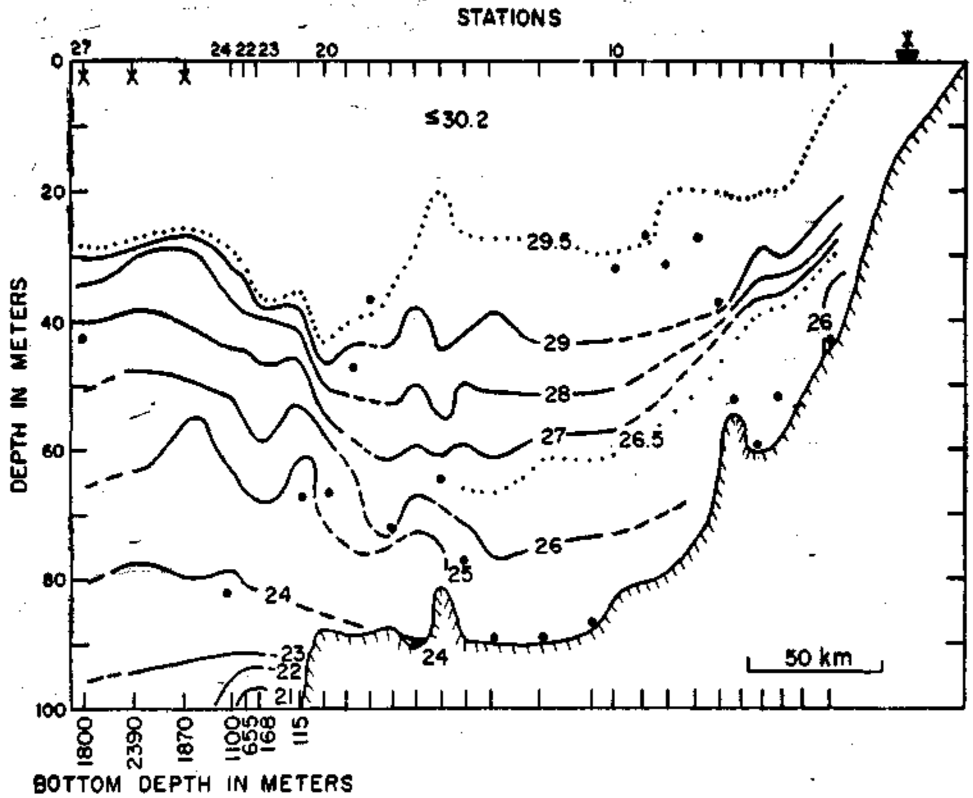

Fig. 3. Temperature section off Bombay, 13 to 14 June 1970. 30° isotherm omitted. Heavy dots indicateend of BT traces. See also Fig. 2.

with small temperature gradients from a second layer of steep gradients, in the range of 25° to 26°C; as a consequence, the isotherms for these temperatures were again close together. Below, a more graduate decrease of temperature was observed but in many stations another steepening of vertical gradients took place near the 20° isotherm.

In late June, on the southward-bound cruise from Bombay past Goa (Fig. 5), the temperatures of the mixed layer had declined by roughly 1°C. The top of the thermocline was found at 35 (30) m to 45 m on the outer continental shelf and the continental slope, *i.e.*, generally deeper than in early June in this area. The dip of the thermocline on the outer shelf was gone. The 26° isotherm in this zone was at approximately 45 m depth but sank on the continental slope (station 11) to 58 m, about the same depth as observed on the nearby stations 104 and 105 in early June. However, the 21° isotherm had risen by approximately 15 m in this area at the end of June.

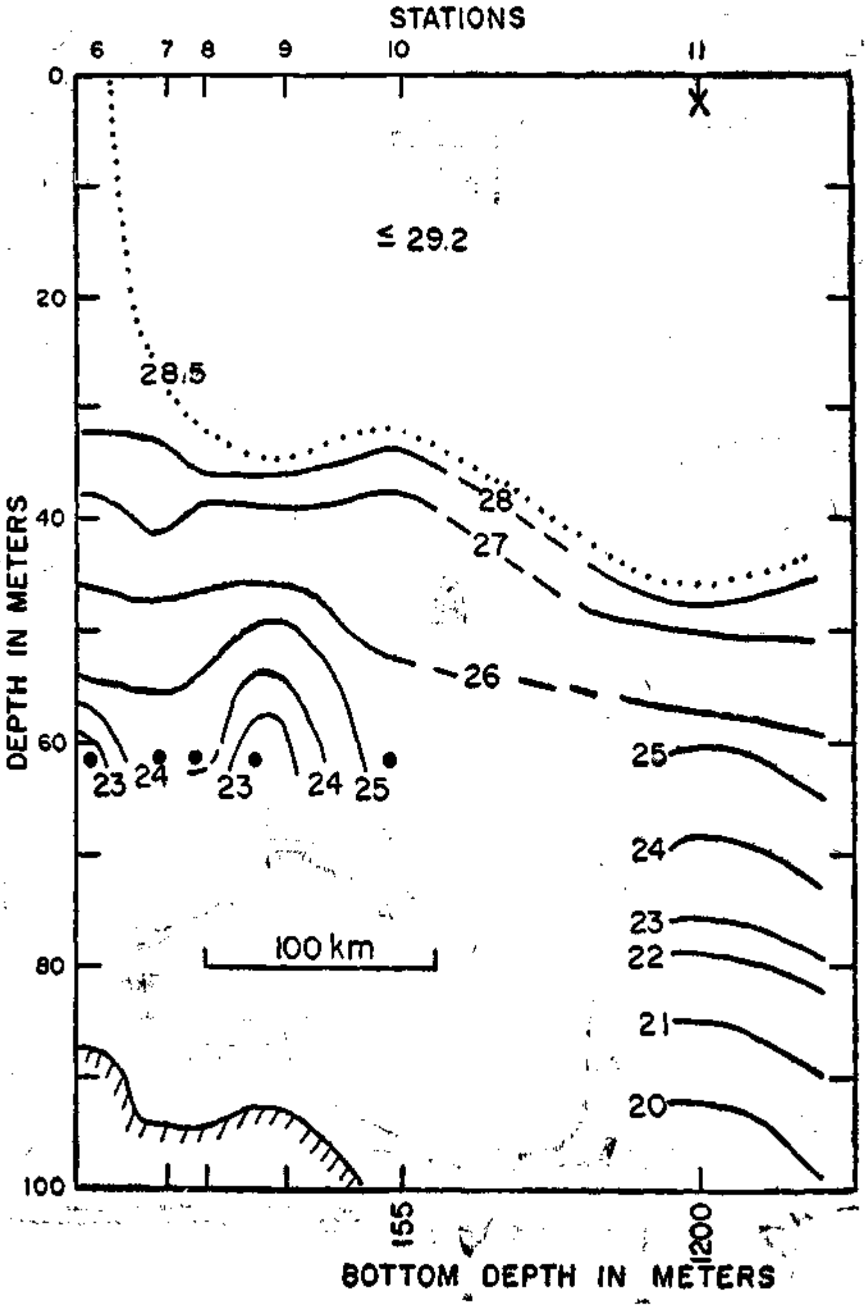

Fig. 4. Temperature section between Bombay and Goa, 28 to 29 June 1970. 29° isotherm omitted. See also Figs. 2 and 3.

Discussion

Wind observations : The wind speed measured in the evenings at Ratnagiri, and Bombay before the arrival of the monsoon during the days when the *OCEANOGRAPHER* passed nearby were similar to the average winds reported by the ship ; this holds to a degree also later for Veraval. It seems reasonable to assume that this was true also in May. Considering the observations at Ratnagiri and Bombay it thus is possible that the winds at sea may have been quite similar (within a factor of two) in strength in the southern and central area studied in each of the periods of three to four weeks preceding the sections in Figs. 2, 3, and 4. The winds were westerly in the first period, and more southwesterly in the second period. As mentioned, the winds of the first period, in the northern part of the area, were approximately twice as strong and more westerly than farther south, but declined shortly before the passage of the ship during the second period. Only small wind-induced changes of the thermocline might therefore be expected during June 1970.

It is obvious that a quasi-synoptic survey of the subsurface temperature (especially the thermocline depth) as presented there would be more profitable if the wind field would be considered quantitatively from synoptic maps (which are available). Even without precise knowledge of the distribution of mass because of the absence of salinity data, more generalization could be expected from it than from the descriptive treatment that the author is able to give.

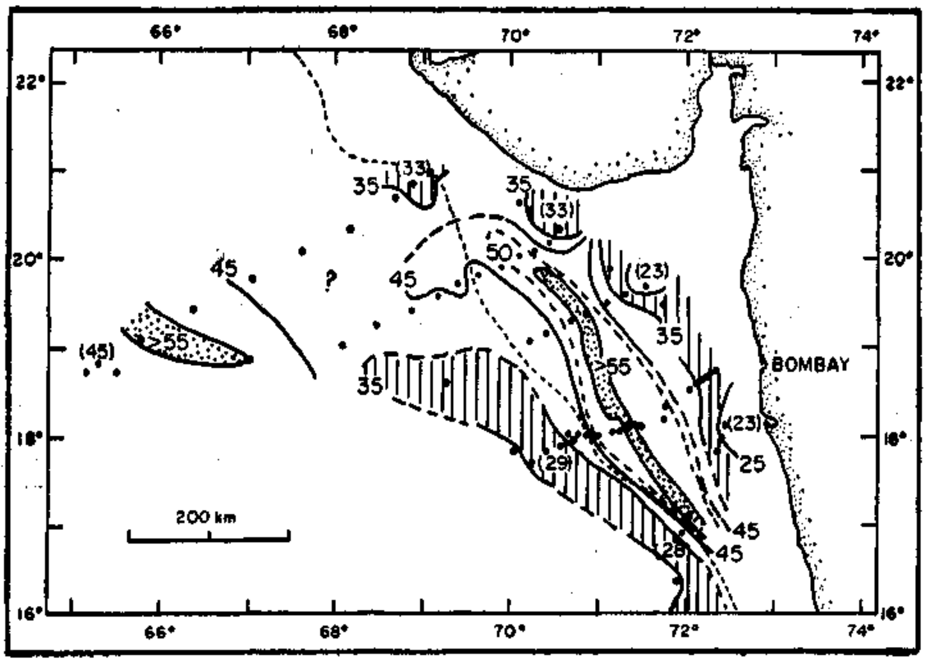

Fig. 5. Depth (m) of 28° isotherm in June 1970. Values in parentheses are actual observations, showing extremes. See also footnote on p. 353.

Water temperatures: The general distribution of subsurface temperatures, especially the presence of cool water at shallow depth in early June, shall be discussed first, followed by a consideration of the changes in time of the subsurface distribution, and finally by a treatment of the topography of the thermocline west and northwest of Bombay. The depth of the 23°C isotherm is emphasized because below the principal thermocline, water of this temperature is likely to have an oxygen content of $\leqq 2$ ml/liter which affects catch rates of some commercially exploited fishes as shown elsewhere (Banse, 1968).

Turning first to the measurements off Goa, it may be mentioned that two BT casts (Nos. 73 and 74) were taken by *MISPILLION* on 17 June 1947 in light winds, between *OCEANOGRAPHER* stations 11 and 12 of 29/30 June 1967 (The later station was about 1° south of the area shown in Fig. 1, on approximately 1,500 m bottom depth). The depths recorded in 1947 for the 28°, 26°, and 23° isotherms (40 to 45 m, 60 to 65 m, and 75 to 85 m, respectively) are close to the depth of the two former isotherms in early June 1967 (station 103 and preceding stations) and of these and the 23° isotherm in late June 1967.

A material rise of the isotherms of early June over the depths in May of other years is to be noted: Figure 2 includes temperature data reported by *ANTON BRUUN* in May 1963 at a similar distance from shore. Temperatures of 26°C were met in early June 1967 at an approximately 45 m higher level than in May 1963 (and roughly 60 m higher than in March 1963, on *ANTON BRUUN* stations close by, see Fig. 1). The 26° isotherm was found in early April 1962 roughly between 75 and 100 m on sections across the shelf off Goa and Malvan (Ramamirtham and Patil, 1966, dates from Central Marine Fisheries Institute, 1969) and around 100 m in a section south of Ratnagiri in mid-May 1962 (Patil *et al.*, 1964). The 23° isotherm was observed on all of these sections somewhat below 100 m but was found in early June 1967 near 80 m at the relatively shallow stations off Goa. Excepting these shallow stations, the differences in levels of the 23° isotherm between early June 1967 and May 1963 are 20 m to 30 m. The isotherm has been recorded during the southwest monsoon (August 1948) inshore at 20 m depth (Banse, 1968). In conclusion, it appears that the seasonal upsloping of isotherms and hence of isopycnals was well underway off Goa in early June 1967. The only other year when any observations were made (1947) seems to have been similar.

Off Bombay, minimal temperatures of 26°C observed in early and mid-June 1967 at 30 to 40 m depth were not as low as the 23° values that can often be found here at these depths during the southwest monsoon. However, the 23° isotherm which occurs in April/May in the area slightly below 100 m was recorded in early June 1967 at about 75 to 85 m (stations 127 to 130, inbound for Bombay) and at about 95 m outbound from Bombay. It is concluded therefore that seasonal upsloping of isotherms and hence of isopycnals inshore near Bombay had advanced moderately by early June 1967.

The coolest water encountered in June 1967 at the 50 m level (23.8°) was found near the shoreward end of the northernmost section (station 59). Similarly, Patil *et al.* (1964) who had worked between Ratnagiri and Veraval in May 1962, had measured the lowest temperatures at shallow levels in this region. They observed water of 25° at 20 m depth off Veraval on a station with 25 m bottom depth but met this temperature at 75 m at the seaward end of their section (station 1006, 210 m deep, approximately 30 km north of *OCEANOGRAPHER* station 42). Although the origin of these low temperatures is still somewhat in doubt*, it is clear from Patil *et al.* (1964, Fig. 8c) that the isopycnals rose strongly toward the coast on 21/22 May 1962 contrary to the observations on the more southerly stations a few days earlier, and also more so than on a section just north of Bombay the next day. The bottom of the surface layer and all isotherms below, down to at least 100 m depth, were highest at the shoreward ends of the northernmost sections of May 1962 and June 1967 as was true for the isopycnals in 1962. Also, surface temperatures near the shore were lower by 1° than at the seaward end of the sections in both years so that a similar distribution of density may have been present in June 1967 as in May 1962. Therefore, upward tilting of isopycnals before the southwest monsoon arrives can be expected off Veraval.

Seasonal upward movement of isotherms and isopycnals on the outer continental shelf before the summer monsoon has been shown by Sharma (1968) to be a regular feature south of latitude 13°N. The rising starts slowly in February/March and quickens from April/May onwards. One might expect this to hold regularly also farther north, at least up to the latitude of Bombay (19°N) because the sea level, corrected for the effect of changes in air pressure, sinks at Bombay from March to May by about 10 cm (Banse, 1968). The lowering occurs in the same time period when in the area off Bombay the average winds at sea turn from northwest (March/April) to west (May) without significant change in strength, and to southwest (June, see Warners, 1952) with strength increased. This should result in progressively less offshore transport of surface water from March to May, and set-up (rise of water level) in June. Also the average density of the upper 50 m water layer declines from March to May to this area by very approximately 0.5 sigma-t units (Data from *METEOR* sections XIII and XIV, February/March 1965, Dietrich *et al.*, 1966; *REQUISITE* sections at 20°30'N and 21°30'N, March 1961; *VITYAZ* stations 4714 and 4717 of April 1960; stations by *CMDR. R. GIRAUD* of April 1961; *ANTON BRUUN* stations 106 and 107, May 1963, all referred to in Banse, 1968; sections by Patil *et al.* 1966, at 18° and 19°N, May 1962). Because actually the sea level sinks, its expected rising must be over-compensated by increase of density below as is similarly the case off Cochin (10°N). This can be anticipated before June also because the general air circulation and the current regime which dominate during the southwest monsoon proper are established well before June; during the monsoon season they result in an uplift of the 23° isotherm by 50 to 75 m over the levels prevailing earlier in the year as shown in 1968. However, the 23° isotherm does not trend upwards in the mentioned hydrographic observations off Bombay from March to May which admittedly are geographically not well distributed. Also there is no uptilting in the sections of Patil *et al.* (1964) off Bombay in May 1962, although this was found off Veraval. No explanation for the apparent discrepancy is available.

In conclusion, therefore, it seems that off Goa, rising of isotherms and isopycnals occurs before June. Off Bombay this has not been observed although before

* While discussing these measurements in 1968 without the benefit of the original data, I had wondered whether pre-monsoonal upsloping of the principal discontinuity layer from offshore had reached 20 m. already or whether the cool water at shallow depths had been part of the peculiar subsurface water mass which is generated by winter cooling in this region and persists above the principal discontinuity layer until the onset of the monsoon. After plotting the t-S relations from the original data (Central Marine Fisheries Research Institute, 1969), I favour the latter explanation. If such water had been encountered also in 1967, the cool water below the warm surface layer in the northernmost area visited would not have been contiguous with that at similar depths off Bombay. The problem cannot be solved without salinity observations.

June denser water must flow in at depth for the stated reasons. In the absence of June data from other years for the 23° (and 26°) isotherms on or near the shelf off Bombay, it is not possible to say whether or not the upsloping and especially the levels of isotherms found by the *OCEANOGRAPHER* prior to the onset of the southwest monsoon of 1967 are the rule. Off Veraval, upsloping of isopycnals can occur in May.

Turning to changes in depths of isotherms between early and late June 1967 on the outer shelf between Goa and Bombay, it was noted earlier that the top of the thermocline had sunk, that the 26° isotherms on the continental slope had stayed at about the same level, but that the 21° isotherm had risen. These changes are documented by only few bathythermograph casts, not exactly at the same bottom depths or distances from shore. It is possible that indeed only small changes had occurred after the initial slight uplifting over the average levels of May ; the wind speeds at sea in each of the preceding periods probably had not been drastically different even if the wind were quite strong during the observations in late June. In the area studied, July is the month with strong winds at sea in the climatological average (cf. Warners, 1952 ; similarly Jayaraman *et al.*, 1962, for Bombay) and it may be that the strong tilting of the thermocline which raises also the 23° isotherm to shallow depths from July onwards is connected with currents induced only then.

Because of the small changes observed in the revisited parts of the area, the sections run between 8 and 21 June were considered to be quasisynoptic. The outstanding feature of the topography of the upper part of the thermocline as indicated by the 28° isotherm is the trough on the outer shelf. The 28° isotherm is lowered by about 20 m. The trough may be a regular feature of the area during this season because a similar temperature pattern, and particularly of density, has been observed also in other years. Earlier in the season, the *METEOR* sections XIV to XVI (possibly also XIII) of February/March 1965, across the shelf between Bombay and Karachi (data from Dietrich *et al.*, 1966) show a belt of relatively light surface water reaching 40 to 60 m depth in the zone above the break of the shelf. The distribution of temperature was less regular and clear than that of density except on section XVI. In middle to late March 1961 relatively light water extended to 20 m at 20°30'N, somewhat beyond the break of the shelf, and 50 m and 20 m above the 100 m isobath, at 21°30'W and 22°40'N, respectively, in hydrographic east-west sections run by *REQUISITE*. In a section at 22°30'N in late April 1961 by *CMDR. R. GIRAUD*, this belt of light (low salinity) water seems to have been shifted seaward by almost 100 km. Finally, hydrographic sections were made in 1962 by Patil *et al.* (1964, *cf.* figs. 9 and 11) from the coast to about 69°30'E. At the 50 m plane, a band of light water extended in a northwest-southeast direction as in 1967 but was displaced by about 50 km to the west. Also from the analytical study of the *METEOR* sections by Düing (1967) and his theoretical treatment, it appears that such a trough is a regular feature in the region.

Lateral movement of this belt of warm water may have caused the peculiar distribution of temperatures near the bottom in June 1952 and 1953 as observed by *TAIYO MARU NO* 17, shortly before the termination of fishing owing to the summer monsoon in the area of concern. Tables 1, 2, 3a and 4 in Banse (1968) show slight increases of temperature in the bottom water towards greater depths, *i.e.*, away from the shore, as well as replacement of relatively cool by markedly warmer water at depths between 35 and 50 m at a time when one might expect the opposite to happen.

Concluding Remarks

Because this paper is a contribution to a symposium, it may be appropriate to add a few words which go beyond the interpretation of the present observations. The remarks are made on the premise that the principal features of the hydrography of the Indian west coast now are known and that hence the exploratory phase is past. Of course, the principal features are not well enough understood quantitatively so that seasonal changes or regional differences cannot be predicted from basic observations like wind or heat balance. However, the theory for doing this is being developed (*e.g.*, Schmitz, 1967 ; Lighthill, 1969).

Based on this premise, I believe we can now anticipate qualitatively what the outcome of a hydrographic study will be before it has begun ; especially it should be possible to anticipate whether a study can result in explanations (in contrast to descriptions among which I count the present paper). In consequence, proper planning of observations is possible including a beforehand evaluation of the approaches to be chosen. It appears to me, then, that further time series of hydrographic surface data for single stations along the coast are very unlikely to yield significant results. Even time series of subsurface observations of temperature and salinity at single stations are unlikely to do this : Of course, it would be useful to learn from subsurface data whether there is regular upwelling off Goa (as contrasted to mere upsloping of isotherms), or to have better descriptive information on the hydrography off Saurashtra as it could be provided by a strategically placed station, or to monitor differences between years, and finally, to have such information from well-studied locations for checking models. However, single stations by their very nature do not lend themselves easily to attempts of numerical explanation of the changes in time observed at these stations. The observations themselves do not permit separating the influence of local change from that of advection, nor do they permit computation of mass transport and its relation to, for example, wind. The minimum effort required for significant time series studies seems therefore to be often-repeated sections across the shelf which should be supplemented by current measurements.

Because upsloping and upwelling off the Indian west coast are not caused by local events—although they may be markedly influenced by them—observations on a larger scale than done so far on the eastern side of the Arabian Sea seem to be necessary for significant advancement of our quantitative understanding and ultimately, for prediction. I am not qualified to say whether a synoptic—*i. e.*, multipleship—survey or several good standard sections run over extended periods were preferable if these are truly alternatives.

The above remarks hold largely for studies of primary productivity too, quite apart from the fact that distribution in space and time of concentrations of nutrient salts or phytoplankton cannot be explained without hydrographic data. Also in this field, theory (of a general nature, not specifically for the Arabian Sea) is advanced enough that the purpose of a study and the likely minimal outcome can be defined before the first observation has been made. Thus, the goals of a planned investigation can be held against the investment of man-power, time, and funds beforehand rather than this evaluation be done with the benefit of hindsight. There are now enough observations available from the Indian west coast that we can strive for explanations instead of further descriptions.

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