J. Mar. biol. Ass. India, 1966, 8 (2): 236-243

ON THE RELATIVE (GEOSTROPHIC) CURRENTS IN THE SOUTH EASTERN ARABIAN SEA*

By C. P. Ramamirtham**
Central Marine Fisheries Research Institute

Introduction

Determination of space distribution of ocean currents in the sea is one of the most important problems in dynamical oceanography. Such studies facilitate the determination of the areas of convergence and divergence in the ocean, which are of important consequence to the fertility and thus to the fisheries of the region (Hela and Laevastu, 1961). Studies regarding current patterns along the west coast of India from hydrographical observations have been made by the Central Marine Fisheries Research Institute, from the data collected on board the research vessels *VARUNA* and, *KALAVA* (Sastry, 1959; Ramamirtham *et al.*, 1960; Jayaraman *et al.*, 1960; Patil *et al.*, 1963). The above-mentioned accounts pertained to a coastal belt of maximum width 150 miles only, and for localised areas around the Laccadives. Moreover, in all these studies the main properties considered for the current studies were temperature and Sigma-T only, as the data collected were not sufficient to permit a detailed study using the method of dynamic computation. During the period November 1962 - January 1963 detailed hydrographic studies were made in the southeastern Arabian Sea, covering a vast region between 11° and 17° N, within the meridians of 70° and 75° E. The observations were extended to deeper waters of 2000-3000 m., and the whole region was covered within a period of nearly one and a half months. Hence it was considered worthwhile to attempt a detailed study of the current patterns from the geopotential topographies of the isobaric surfaces, and the data collected were quite sufficient for the purpose.

Observations and discussions

The determination of currents from mass distribution can be done from observations of salinity and temperature in a much easier manner than direct measurements by current meters. For the present study the specific volume anomalies for all the samples upto a depth of 1000 m. were calculated, using the oceanographic slide rule, and the dynamic height anomalies by numerical integration using the formula $\Delta D = \int_{p_1}^{p_2} \alpha \, . \, dp$. The 1000 db. surface was selected as the arbitrary level of no motion, as the distribution of specific volume anomaly at this depth revealed minimum movement. The dynamic height anomalies at each isobaric

---

* Published with the kind permission of the Director, Central Marine Fisheries Research Institute, Mandapam Camp.

** Present address: Central Marine Fisheries Research Substation, Ernakulam.

surface were calculated relative to the above level of no motion, and from these the geopotential topography of each isobaric surface was charted out. These are presented in Figs. 1-5. Montgomery (1937), suggested the isentropic analysis and proposed to use the Sigma-T surfaces as the best substitutes for the isentropic surfaces. Such studies have been made in the present instance also, and the topographies of selected Sigma-T surfaces are presented in Figs. 7 and 8.

Discrepancies occur between the streamlines of geostrophic flow represented by surface dynamical topography and the trajectories of surface water movements determined by drifts of ships, and some of these discrepancies originate from the fact that friction is neglected in the method of dynamic computation. But Hidaka (1957), has pointed out from mathematical considerations that when a thermocline exists, much attention need not be paid to the influence of eddy viscosity on the geostrophic flow. A well stratified thermocline exists throughout the investigated area, and thus frictional considerations have been avoided. Moreover the studies pertain to deeper waters only.

One of the difficulties of the geostrophic computation of ocean currents is that the method fails at or near the equator because the Coriolis parameter vanishes here. Due to this variation df/dy (the Rossby parameter) an overall inset map for the interpolation of current velocities from distance between contours in the horizontal, will not be accurate for a vast latitudinal region as in the present studies. The latter pertain to a region from 11° N, to 17°N. Hence instead of the inset map mentioned earlier, velocities at specified latitudes were calculated for one degree latitude distance between contours of 0.1 dynamic meter difference. These are given on the chart representing the surface dynamical topography, and are the same for all the depths, and are distinguished by the underlined numerals near the latitudes. Although this does not give a complete idea of the velocity distribution, the intensities of movements can easily be judged.

In general, the geopotential topographies of all the isobaric surfaces from sea surface to 150 m. depth are similar, with slight regional variation in structure and current velocity. Thus at surface (Fig. 1), a general, weak, northward drift is found between 11° and 13° N, which deflects northwestwards around 13°N, and attains good velocity. Between 14° and 15° N, the flow is mainly northerly, and another northwesterly deflection is conspicuous at 15°N. Maximum velocity for this drift is attained around 16°N, and an anticyclonic eddy seems to develop to the northeast of the regular drift.

A similar pattern of circulation is found at 10, 20, 30 and 50 m. depths. As the geopotential topographies of the above surfaces are mostly similar to that of the sea surface the relevant charts are not presented. The temperature distribution at these depths were studied, but a comparison of the thermal structures and dynamic topographies was not at all satisfactory, as far as the dynamics of the region were concerned. The regular northward drift was not evident from a study of the temperature gradients. Hence it is presumed that the distribution of salinity has got notable influence in the modification of the current patterns, in the upper layers above the thermocline.

Such discrepancies have disappeared further below at 75 and 100 m. depths, where the temperature discontinuity layer started usually. The dynamic topography of the 100 db. surface is given in Fig. 2. With lower values of velocity, the main trend of circulation is again the same as at surface. Another eddy system which was weakly developed at surface is present at 100 db. surface also. This system is found throughout the depths from the surface. One particular feature regarding the 75 and 100 db. surfaces is that the thermal field and the dynamic topographies agree well as far as the dynamics of the region is concerned. Thus the temperature distribution at 100 m. (Fig. 6) depth shows the presence of westward temperature gradients especially north of 13°N, which suggest a northward movement. South of this latitude also the gradients are visible even though the intensity is less.

The trend of the circulation pattern is maintained at 200 db. surface (Fig. 3) and the movements are much weaker compared to the upper levels. Further below at 400 m. (Fig. 4) the northward movement north of 13° N, develops into a circulatory system which is rather weak. At 800 db. surface (Fig. 5) negligible gradients in the dynamic height anomalies are found and it may be remembered that this is closer to the level of no motion assumed.

In order to have a better idea of the circulation pattern in the regions concerned, isentropic studies were made for a few selected surfaces, according to the method of Montgomery (1937). The topographies of the 23.5 and 24.5 Sigma-T surfaces have been charted out and presented in Figs. 7 and 8. Considering the topography of the 23.5 Sigma-T surface (Fig. 7) it is seen that north of 13°N, where swift geostrophic currents were noted, the isentropic surface slopes steeply downwards towards east. Further confirmation for the regular relative currents may be had from an examination of the topography of the 24.5 Sigma-T surface (Fig. 8). As may be seen, the slope of the isentropic surface is weak in the region south of 13°N. But in accordance with the relative currents, north of this parallel steep eastward downslope is observed indicating good northward drift. Similar is the case with the topography of the 25.0 Sigma-T surface, which also was charted out. A study of the distribution of salinity over the isentropic surface showed that there is a gradient in salinity eastwards although it is weak. This further is in accordance with the mass distribution found from the topographic charts.

The dynamical studies within the latitudes of 8° and 11°N, also were carried out along with the present studies. In these regions the Laccadive-Maldive chain of islands may have their influence on the circulation pattern. A divergence zone towards the western sector around 71°E. meridian and a convergence zone around 74°E. meridian, have been found. Anyway more detailed observations are necessary to confirm these circulation patterns in the vicinity of these islands, and hence this area has not been included in the present topographic charts.

It has been reported earlier that the period November-January is the sinking period when a northward flow exists along the coastal region, (Ramamirtham *et al.* 1960). Such a notable movement has been found from the coastal data collected along with the present one. From the present studies it may be seen that this flow exists in the offshore regions as well, with good intensity. It may be observed that the dynamic topographies, topography of the isentropic surfaces, and the thermal fields present comparable type of circulation only below a depth of 75 m. The observation that, in the mixed layer, thermal field and dynamical topographies do not reveal similar pattern of circulation may be due to the result of the influence of salinity on the mass distribution.

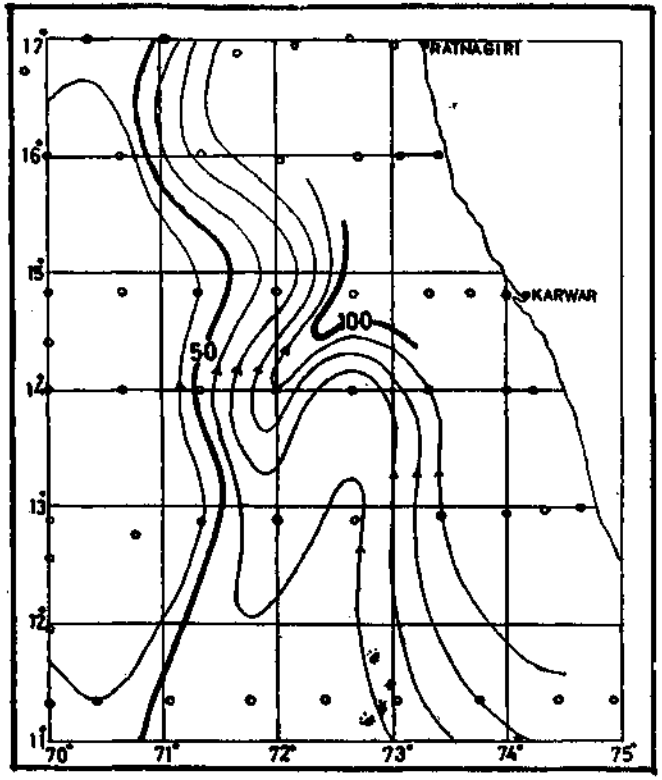

FIG. 1. Topography of the 23·5 Sigma—T surface contours for every 10 m. Also given the geographical positions of the stations investigated.

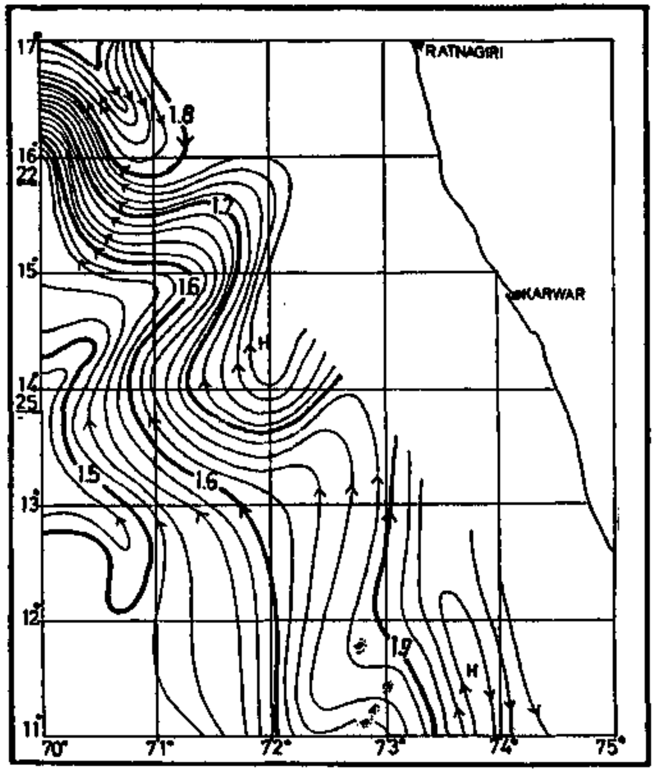

FIG. 2. Geopotential topography of the sea surface relative to the 1000 db. surface. Also given velocity of currents in cm./Sec. (underlined numerals near latitudes) for 1° lat. distance between contours of 0·1 dyn. meter difference.

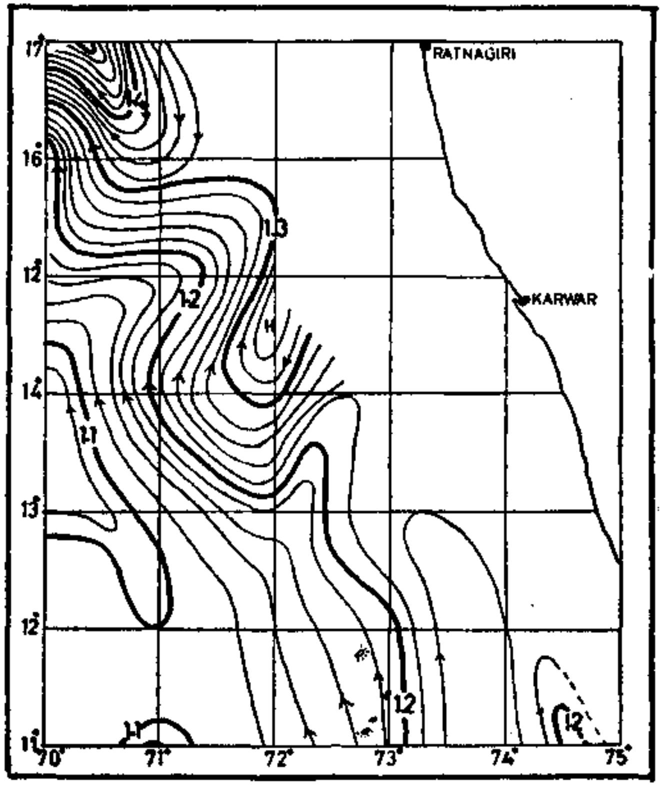

FIG. 3. Geopotential topography of the 100 db. surface relative to the 1000 db. surface.

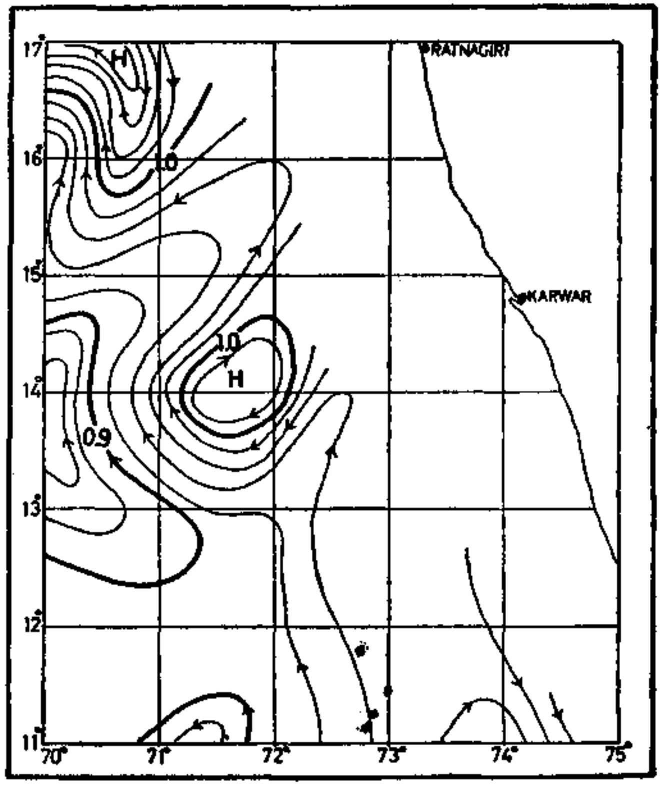

FIG. 4. Geopotential topography of the 200 db. surface relative to the 1000 db. surface.

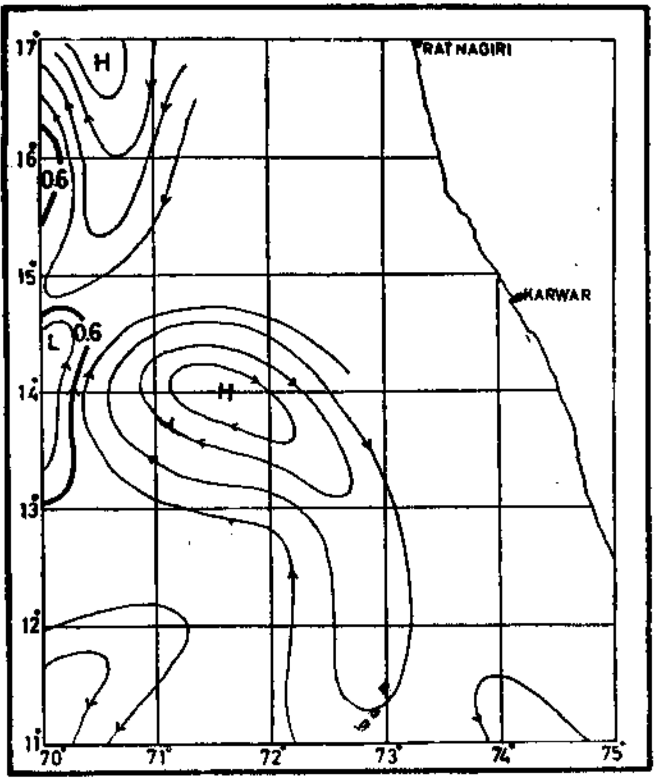

FIG. 5. Geopotential topography of the 400 db. surface relative to the 1000 db. surface.

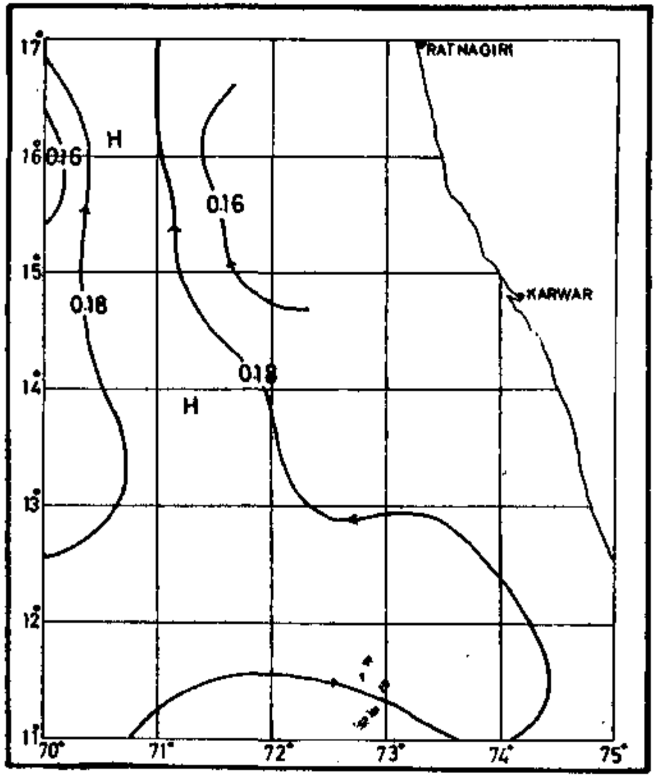

FIG. 6. Geopotential topography of the 800 db. surface relative to the 1000 db. surface.

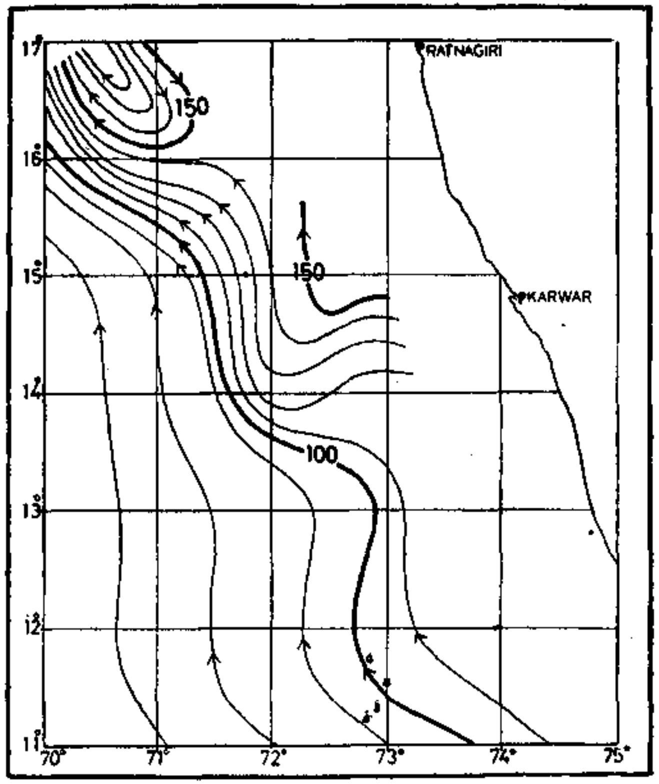

FIG. 7. Topography of the 24.5 Sigma-T surface contours for every 10 m.

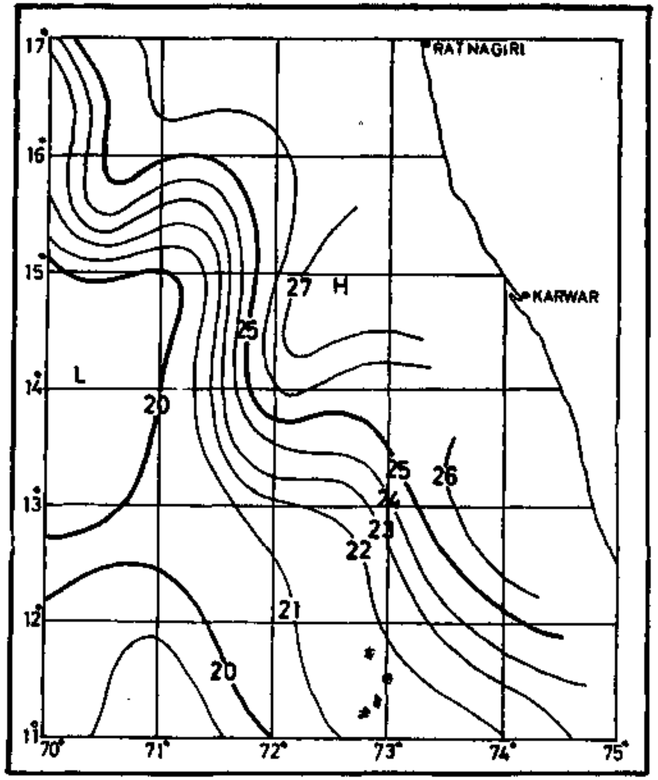

FIG. 8. Distribution of temperature over the 100 db. surface.

SUMMARY

In this account, the relative (geostrophic) currents in the southeastern Arabian Sea are discussed. The main feature of the circulation is a northward movement with northwest deflection around 13° and 15° N. latitudes. The drift has good velocity, the maximum being attained in the region between 16 and 17° N. latitudes. The isentropic studies made for the investigational region confirmed the circulation pattern deduced from geopotential topographies. It is found that the dynamic topographies, topography of the isentropic surfaces and the thermal fields present comparable type of circulation only below a depth of 75 m., and this discrepancy in the upper layers (0-50 m.) is inferred as due to the effect of salinity.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Dr. S. Jones, for his keen interest in these investigations. Thanks are also due to Dr. R. Raghu Prasad for his encouragement, and to Dr. V. V. R. Varadachari for his helpful suggestions given during the course of the work. The help rendered by Sri D. Sadananda Rao in preparing the text-figures is also gratefully acknowledged.

REFERENCES

HELA ILMO AND LAEVASTU TAIVO. 1961. *Fisheries Hydrography* : 43 *and* 51. Fishing News (Books)Ltd. London.

JAYARAMAN, R., RAMAMIRTHAM, C. P., SUNDARARAMAM, K. V. AND ARAVINDAKSHAN NAIR, C. P. 1960. Hydrography of the Laccadive offshore waters. *J. Mar. biol. Ass. India*, 2(1) : 24-34.

HIDAKA KOJI. 1957. Influence of friction on geostrophic currents. *Journ. Oceanogr. Soc. Japan*, 13(2) : 37-49.

MONTGOMERY, R. B. 1937. A suggested method for representing gradient flow in isentropic analysis. *Bull. American Meteorological Soc.*: 210-212.

PATIL, M. R. AND RAMAMIRTHAM, C. P. 1963. Hydrography of the Laccadive offshore waters-A study of winter conditions. *J. Mar. biol. Ass. India*, 5(2) : 159-169.

RAMAMIRTHAM, C. P. AND JAYARAMAN, R. 1960. Hydrographical features of the continental shelf waters off Cochin during the years 1958 and 1959. *Ibid.*, 2(2) : 199-207.

SASTRY, A. A. R. AND MYRLAND, P. 1959. Distribution of temperature, salinity, and density, in the Arabian Sea along the south Malabar coast (South India) during the post-monsoon season. *Indian J. Fish.*, 6(2) : 223-255.