CHAPTER II
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DISTRIBUTION OF PROPERTIES ON POTENTIAL THERMOSPERIC ANOMALY SURFACES

The spatial distributions of potential temperature and salinity in the intermediate layers of the ocean reflect the combined effect of advection and mixing of different water masses. The large scale distributions of these conservative properties often indicate qualitatively the current structure in the oceans and therefore the circulation must be consistent with the distributions of these properties.

The topography of 100, 80, 60 and 40-cl/t surfaces, and the distribution of acceleration potential relative to 2,000 db and the salinity on these surfaces are shown in Figs. 4 to 15.

2.1. The 100-cl/t surface
2.1.1. Topography

The topography of the 100-cl/t surface deepens to a conspicuous trough structure along 1°-2°N between 46° and 55°E and from 68° to 74°E, with depths exceeding 600 m. These troughs are possibly associated with the northern boundary of the westward flowing undercurrent, discussed by Luyten and Swallow (1976) and Luyten et al.
(1980). Off the coast of Somalia, at about 7°N from 53° to 55°E a prominent trough, surrounded by ridges on the east, west and south is observed. The southern ridge is located at about 4°-5°N along 54°E. These ridges and the trough may be associated with the boundaries of the southward flowing undercurrent carrying the high salinity water and northward flowing low salinity water (Quadfasel and Schott, 1982). Off the southwest coast of India, a trough is noticed around 11°N between 69° and 74°E and a ridge centered around 9°N, 73°E. These, probably, indicate the boundaries of the southerly flow as confirmed on the distribution of acceleration potential.

Besides, there are a number of troughs and ridges in the depth range of 450 to 650 m in the various regions of the Arabian Sea on this surface. These ridges and troughs suggest the possible occurrence of cyclonic and anticyclonic eddies. Duing (1970) found several cells of low and highs in the dynamic topographic charts which he attributes to the cyclonic and anticyclonic eddies at the surface in the Arabian Sea.
The depth of 100-c1/t surface in the central Arabian Sea is more or less uniform with values slightly less than 500 m. Another region of fairly uniform depth is between 4° and 8°N from 66° to 74°E. In general, the depth of 100-c1/t surface varies from slightly less than 450 m to more than 650 m.

2.1.2. Geostrophic flow

The circulation suggested by the topography of this surface is more or less agreeing with the pattern of acceleration potential. A westerly undercurrent near the equator is clearly indicated except of 45°E and east of 75°E. This appears to be the westward flowing intermediate equatorial current. The westward current below the eastward undercurrent is named as Intermediate Equatorial Current (Hisard and Rual, 1970) in the Pacific Ocean. Its presence in the Indian Ocean was identified from the current meter observations by Luyten and Swallow (1976) at 0°, 53°E. Prominent westward flow at these depths was reported by Leetmaa et al. (1982). A westward flowing undercurrent with jet-like structure is known to exist along the equator between 1° 30'N and 1° 30'S (Luyten and Swallow, 1976; Luyten et al., 1980). North and south of the westward undercurrent, an eastward flow of about 200 km wide, having a vertical structure similar to that of the
westward undercurrent at the equator was reported by
Spencer et al. (1980).

Off the coast of Somalia, meridional flow is
predominant. This can probably be attributed to the
southward flowing undercurrent off Somalia. Measurements
by Swallow and Bruce (1966) at 8° 30'N indicate the
presence of southward flowing undercurrent. Observations
with moored instruments (Duing, 1977; Schott and
Quadfasel, 1982) also show strong southward subsurface
flow. Such an undercurrent is not seen south of 4°N and
north of 8°N (Leetmaa et al., 1982). The existence of
the undercurrent at different times of the year suggests
that it is a permanent feature of the subsurface
circulation rather than a transient phenomenon
(Leetmaa et al., 1982). The presence of a southward
flowing current beneath the northern part of the Somali
Current is also documented in a 2½ year time series
observations of currents at moored stations near 5°N,
about 30 km off the Somali Coast (Quadfasel and Schott, 1983).

An anticyclonic flow pattern is noticed near the
southern Somali Coast between 1° and 3°N from 46° to 49°E
that can, probably, be attributed to the recirculation of
the westward flowing equatorial undercurrent near the
East African Coast. Quadfasel and Schott (1982) report that equatorial water which is nearly homogeneous in the vertical is carried by the westward flowing equatorial undercurrent and before it reaches the East African Coast, it is recirculated to the east just north and south of the equator. These subsequently drift as anticyclonic subsurface eddies away from the equator into the northern and southern parts of the Somali Basin.

A southerly flow is observed off the southwest coast of India. Wyrtki's maps (1971) did not show such a flow at 500 m relative to 3,000 db, perhaps, due to lack of adequate number of stations or might have been masked in the averaging.

Zonal flow is predominant in the northern Arabian Sea while northerly prevails off the southeast coast of Arabia and at the mouth of Gulf of Oman.

Similar to the topography map, the distribution of acceleration potential on 100-c1/t surface exhibits a number of high and low values in different regions of the Arabian Sea. The occurrence of the complex pattern of highs and lows are indicative of anticyclonic and cyclonic eddies and are seen in the earlier works of Swallow and Bruce (1966), Bruce (1968), Bruce (1970) and Duing (1970),
Duing (1970) stated that even if one takes into account the fact that the data are of very heterogeneous quality, there can be little doubt that this complex distribution really exists.

2.1.3. Salinity

The salinity distribution on the 100-cl/t surface shows significant spatial variation. The salinity values range from 34.94 to 35.89%. The lower salinities are encountered near the equator because of the influence of low salinity water from the southern hemisphere as well as advection of equatorial Pacific Ocean Water that flows along the South Equatorial Current to the western Indian Ocean (Wyrtki, 1957, 1961; Taft, 1963; Sharma, 1972; Sharma et al., 1978). Salinity values above 35.80% are noticed in the northern Arabian Sea. Relatively high salinity values observed in the central western Arabian Sea are clearly due to the influence of Red Sea Water.

The isohalines are zonal near the equator, whereas they are meridional off the northern Somali Coast. Tongue-like structure observed off the northern Somali Coast suggests the southward advection of Red Sea Water (Quadfasel and Schott, 1982). Off the west coast of India, similar tongue-like structure is noticed indicating southerly flow as found on the distribution of acceleration potential.
Another interesting feature is the presence of two cells of high salinity water, one along the southern Somali Coast and the other along the southwest coast of India. Rapid decrease of salinity from the east of the Gulf of Aden towards south and southeast of Socotra Island may be due to horizontal advection. In general, salinity decreases from north to south and from west to east on this surface.

2.2. The 80-cl/t surface

2.2.1. Topography

The topography of the 80-cl/t surface closely resembles that of 100-cl/t surface in many respects. The troughs and ridges associated with the boundaries of the currents observed on the 100-cl/t surface are all found on this surface also. The depth of the surface, in general, varies from 600 to 925 m.

A comparison between the topography of 100 and 80-cl/t surfaces shows relatively lower thickness (less than 200 m) between these two surfaces off the southern Somali Coast, east of the Gulf of Aden, central Arabian Sea and off the west coast of India. Such a condition indicates higher stability of the waters between these two isanosteric surfaces. On the contrary, greater thickness (more than 250 m) is found near Socotra Island, northern and southeastern Arabian Sea where the vertical stability is less.
2.2.2. Geostrophic flow

The flow pattern on 80-cl/t surface is, in general, similar to that on the 100 cl/t. The westward undercurrent near the equator, easterly flow north of it, southward undercurrent along the Somali Coast, anticyclonic flow near the southern Somali Coast and southerly flow along the southwest coast of India are all evident on 80-cl/t surface also. The occurrence of complex pattern of lows and highs in the distribution of acceleration potential suggests the presence of cyclonic and anticyclonic eddies.

2.2.3. Salinity

The distribution of salinity on the 80-cl/t surface exhibits significant spatial variation just as on 100-cl/t surface. Salinity varies from 34.91 to 35.78%. The regions of occurrence of lower and higher salinities are same as that of the upper surface. Most of the other features, noticed are similar to that of the 100-cl/t surface. However, the isohalines display meridional orientation in the southeastern Arabian Sea and are almost meridional in the northern Arabian Sea. Besides, cells of low and high salinities are noticed in different regions of the Arabian Sea.
Fig. 8 Distribution of Acceleration Potential (joules/kg) Relative to 2000 db at the 80 clt Surface
The horizontal gradients in salinity are relatively higher off the Somali Coast, east of the Gulf of Aden and eastern Arabian Sea, coinciding with the lower thickness (less than 450 m) between the topography of the 100 and 60-cl/t surfaces, where horizontal mixing predominates due to higher stability. Similarly less horizontal salinity gradients in the northern, central and southeast Arabian Sea where greater thickness (more than 500 m) between the 100 and 60-cl/t surfaces indicating the presence of relatively less stratified water are noticed. Such a situation arises out of vertical mixing.

2.3. The 60-cl/t surface

2.3.1. Topography

The topography of the 60-cl/t surface resembles that of the 100 and 80-cl/t surfaces in many respects. The troughs and ridges associated with the boundaries of the currents found on the upper two surfaces are all evident on this surface, but their positions are slightly altered. Contrary to the upper two surfaces, the topography of this surface in the central Arabian Sea is uniform. The depth of the surface, in general, varies from 860 to 1,260 m.
The thickness of the layer between 80 and 60-cl/t surface is more (greater than 300 m) off the Somali Coast, southeast of Socotra Island, central and southeastern Arabian Sea indicating lower stability between these surfaces. Relatively lower thickness (less than 250 m) is noted on the eastern side of Gulf of Aden and in the eastern and northern Arabian Sea suggesting more stratified water between these two isanosteric surfaces.

2.3.2. Geostrophic flow

The flow pattern more or less shows similar features as on the upper two surfaces, though the intensity is comparatively less. The zonal flows near the equator and meridional flows along the Somali Coast and southwest coast of India are observed on this surface. Cyclonic and anticyclonic eddies are also noted as on the upper two surfaces. Unlike on the two upper surfaces, there are strong meridional components in the northern Arabian Sea on 60-cl/t.

2.3.3. Salinity

The salinity distribution on the 60-cl/t surface displays remarkable spatial variation, similar to the two upper surfaces. The salinity values range from 34.83 to 35.74%. The lower and higher values of salinity are found near the equator and in the central western Arabian Sea respectively, like in the upper two surfaces.
FIG. 11 DISTRIBUTION OF ACCELERATION POTENTIAL (joules/kg) RELATIVE TO 2000 db AT THE 60-cf/m SURFACE
The pattern of isohalines near the equator is almost similar to that found on 80-cl/t surface. They exhibit an irregular pattern in the central Arabian Sea. The high salinity noticed off the northeastern Arabia Coast which is a predominant feature at 100 and 80-cl/t surfaces is weakened on this surface.

The horizontal salinity gradients are comparatively higher from east of Gulf of Aden to 60°E (around Socotra Island) and central Arabian Sea, matching with the lower thickness (less than 700 m) between the topography of 80 and 40-cl/t surfaces, where the prominence of horizontal mixing occurs due to higher stability. Less horizontal salinity gradients are noticed at northern and southeastern Arabian Sea indicating the predominence of vertical mixing which agrees with relatively greater thickness (more than 800 m) between 80 and 40-cl/t surfaces because of less stable water.

2.4. The 40-cl/t surface

2.4.1. Topography

The topography of the 40-cl/t surface exhibits significant differences from that of the upper three surfaces. The depth of this surface is very uneven compared to the other surfaces and hence contouring is
done with 100 m interval. The depth of this surface ranges from 1,230 to 1,730 m. In the central Arabian Sea, a trough with depth exceeding 1,600 m is observed while no trough is found on the upper three surfaces. Alternate troughs and ridges are noticed along the northern Somali Coast and the central and southwest coast of India.

The thickness of the layer between 60 and 40-cl/t surfaces reveals relatively lower thickness (less than 500 m) in the region east of the Gulf of Aden around Socotra Island and central Arabian Sea indicating stable waters between the two isanosteric surfaces. The thickness is comparatively high (more than 550 m) off the southern Somali Coast and eastern Arabian Sea suggesting that waters are less stratified.

2.4.2. Geostrophic flow

The circulation noticed on the 40-cl/t surface displays remarkable differences from that of the upper three surfaces. The westerly flow near the equator which is a conspicuous feature of the 100, 80 and 60-cl/t surfaces is completely absent on this surface. Instead, meridional components of flow are evident near the equator. This weak northerly flow pattern suggests the advection of
water from the southern hemisphere. Warren et al. (1966) found that the deep waters of the Somali Basin are filled with the Circumpolar Water and indicated that the flow is weak and not well defined. Northward advection of cool, less saline water from the south to the northern Indian Ocean was suggested by Warren (1978, 1981).

The southward undercurrent found along the Somali Coast on the upper three surfaces is restricted to the northern Somali Coast between 9° and 7°N with much reduced strength. As on the upper surfaces, anticyclonic flow pattern along the southern Somali Coast and southerly flow along the southwest coast of India are noted with reduced intensity. Unlike the upper three surfaces, the meridional components of currents are more prominent than the zonal components on this surface.

2.4.3. Salinity

The spatial variation of salinity on the 40-cl/t surfaces is much less compared to the upper three surfaces. The salinity varies from 34.78 to 35.33%. The lower salinities are observed between 1° and 7°N whereas higher values are noticed in the northern Arabian
Sea. The zonal pattern of isohalines found on the upper three surfaces is almost absent and is replaced by meridional pattern indicating the northward movement of low salinity water from the south. Warren et al. (1966) reported the northward advection of water into the Somali Basin from the south.

Uniform salinity values are found off the Somali Coast whereas relatively higher values are observed in the central western Arabian Sea. Cells of comparatively high salinity are also found in the northern Arabian Sea.