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Some details of upwelling off the Somali and Arabian coasts'

J. G. Bruce

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

ABSTRACT

Surface temperature and salinity maps from measurements during the period of maximum coastal upwelling in the Arabian Sea are given. The region of coldest, temperature <14°C, and freshest, salinity <35.15‰, surface water off Ras Mabber (9°N Somali coast) shifted northeastward during a ten-day period. Off the Arabian coast the upwelled water was not as cold (minimum, 18°C) or fresh (minimum, 35.7‰) and was found between 16°N and 20°N.

In the northwestern Indian Ocean during the northern summer monsoon, particularly strong upwelling occurs over a large area along the Somali and Arabian coasts. The commencing of upwelling is evident on both coasts in late April or early May; it is greatest in July and August, and continues until early October (Koninklijk Nederlands Meteorologisch Instituut, 1952). As most atlases draw on data that tend to be widespread in time and position and then must be averaged to depict the properties of a region, many details may be lost. An exception is the Wyrtki (1971) atlas which presents unsmoothed individual monthly surface temperature observations for the entire Indian Ocean for 1963. With the growing interest in coastal upwelling and the associated circulation of the coastal currents, it was felt worthwhile to make available the surface temperature and salinity data from approximately 1060 stations during the southwest monsoon in 1963 off the Arabian coast (Discovery, cruise 1) and in 1964 off the Somali coast (Discovery, cruise 3; Argo, cruise DODD 1). Data are from surface bucket samples at bathythermograph or hydrographic stations and give the most detailed coverage to date of both regions at approximately the period of greatest upwelling during a single season.

The measurements off the Somali coast have been separated into two sets of maps: 17–23 August 1964 (Figures 1 and 2), and 28 August to 5 September

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Figure 1. Surface temperature, °C, in region of maximum upwelling off Somali coast. Data from *Argo*, cruise DODO vi, 17–23 August 1964 and *Discovery*, cruise III, 17–19 August 1964.

Figure 2. Surface salinity, ‰, in region of maximum upwelling off Somali coast. Data from *Argo*, cruise DODO vi, 17–23 August 1964 and *Discovery*, cruise III, 17–19 August 1964.

Figure 3. Surface temperature, °C, in region of maximum upwelling off Somali coast. Data from *Discovery*, cruise III, 28 August to 5 September 1964.

Figure 4. Surface salinity, ‰, in region of maximum upwelling off Somali coast. Data from *Discovery*, cruise III, 28 August to 5 September 1964.
1964 (Figures 3 and 4) because changes of position of both the region of upwelling and the structure of the east-turning Somali Current occurred within this period (Swallow and Bruce, 1966). It has since been shown that large shifts in the path of the current and the associated region of maximum upwelling may occur over periods on the order of a month (Bruce, 1973; Szekielda, 1970). During the first period (Figure 1) the coldest water, temperature \(< 16^\circ C\), extended from about 8°30'N (where strong horizontal thermal gradients of 0.6°C/km were found) northeastward along the coast to 10°N, encompassing an area of 8 x 10^3 km^2. About 10 days later (Figure 3) the cold water clearly had shifted, extending farther northward to the latitude of Ras Hafun, although the area of surface temperature \(< 16^\circ C\) was still nearly the same. The 20°C isotherm, which might be used to approximate the northern bound of the east-flowing Somali Current, shifted from about 9°N (Figure 1), northward to nearly 10°N (Figure 3) during the interval. The freshest water (with salinities \(< 35.15, > 35.10\%/oo\)) occurred inshore along the coast as far north as the southern bound of the cold water (latitude of Ras Mabber) and thence extended offshore in a narrow band along the edge of the current (Figures 2 and 4). The maps further suggest that small branches of the Somali Current might have proceeded northward: in Figures 1 and 2, just along the shore to the northeast of Ras Hafun and between 10°N and 11°N along 52°40'E the surface water maintained the relatively fresh and cold characteristics of the current in a region considerably north of the main path of the offshore current.

Another feature which underwent a change during the interval was the warm, more saline water east of 53°E between 9°N and 12°N. It extended farther westward during this time, and the horizontal temperature and salinity gradients along its southwestern edge intensified (Figures 3 and 4).

The surface temperature map off Arabia indicates a region of relatively cold water extending along the coast from just south of Mirbât northeast to about 22°N (Figure 5) from 25 June to 21 July 1963. A more detailed survey was next made from 29 July to 4 August 1963 of the water where the greatest upwelling appeared to be occurring between 17°N and 19°30'N (Figure 6). Here the area of surface water with a temperature \(< 20^\circ C\) was on the order of 12 x 10^3 km^2. Since surface salinity observations were obtained only on hydrographic stations on this cruise (Figure 7), we do not have detail corresponding to the temperature data. However, a region of relatively low salinity, \(< 35.7\%/oo\), is indicated in approximately the location of the coldest surface water. In general the surface water off the Arabian coast was not as cold or as fresh as that off the Somali coast, nor did there appear to be regions of strong horizontal gradients such as those off Ras Mabber. The weak trough of cold water occurring between 21°N, 60°E and 19°N, 62°E is somewhat similar to the cold trough extending offshore from the Somali coast between 9°N and 10°N, although there are not enough data for clear definition. It is possible that the
Figure 5. (upper) Surface temperature, °C, off Arabian coast. Data from Discovery, cruise I, 25 June to 21 July 1963.

Figure 6. (middle) Surface temperature, °C, in region of maximum upwelling off Arabian coast. Data from Discovery, cruise I, 29 July to 4 August 1963.

Figure 7. (lower) Surface salinity, ‰, off Arabian coast. Data from Discovery, cruise I, 25 June to 18 July 1963.
weak trough might be associated with the high cell shown in the geopotential
topography from data during this monsoon (Bruce, 1968).

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