Historical evidence for two gyres in the Somali Current

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ABSTRACT

Surface currents and some surface temperatures in the Somali Basin have been plotted for May and June of each year from 1900 to 1973 when any data were available. A current pattern containing two clockwise gyres, one situated south of 5N, the other between 5N and 10N, was usually present in June. It is similar to the one observed in a detailed survey of the Somali Current in 1979. Some evidence is presented suggesting that the timing of the development of the gyres, in relation to changes in winds, was similar in other years to the sequence observed in May and June 1979.

1. Introduction

The traditional description of the Somali Current in the southwest monsoon, for example that given by Findlay (1866), has the boundary current running northeastward up the coast of East Africa, increasing in speed and width north of the equator, and turning offshore near 10N. Much of the increased transport in the northern part of the boundary current is recirculated in an eddy situated between latitudes 5N and 10N, and called the "great whirl" by Findlay. In some years the boundary current, or at least a large part of it, has been seen turning offshore at a lower latitude. Bruce (1973) found the current leaving the coast near 6N in August 1970, much of it recirculating to the south of that latitude, and another separate eddy to the northeast. The two eddies could be distinguished by their near surface salinities, the southern one being fresher. More recently Bruce (1979), discussing an XBT section off Somalia occupied many times during 1975-8, found that the "great whirl" was present (as a persistent strong depression of the shallow isotherms) between approximately 5N and 10N every summer, and another clockwise eddy could be seen at the same time south of 5N in 1976. In the other three years, the southern eddy was not evident. Once the pattern was established in May or early June, it appeared to intensify with only minor changes of position. This led to speculation that there might be "single gyre" years and "two gyre" years.

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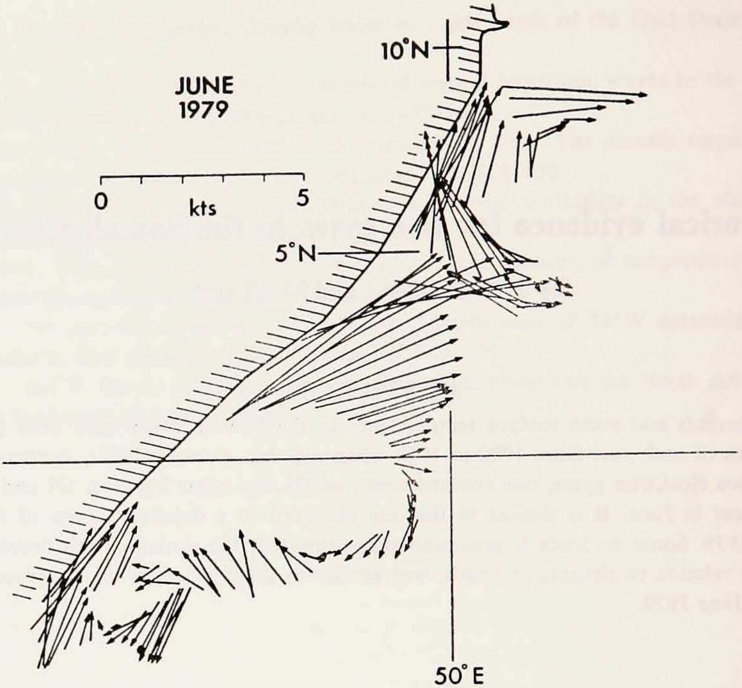

Figure 1. Surface currents observed by the R.R.S. *Discovery* in the Somali Basin in June 1979. The center of each arrow is at the midpoint of observation.

In 1979, when the Somali Current was explored during the Global Weather Experiment, the northern limit of the strong boundary current from the south was seen to move up the coast from the equator to 3N about the second week of May, the current turned offshore there and part of it formed a low latitude gyre. A separate eddy developed *in situ* between 5N and 10N in mid June (Düing *et al.*, 1980). That pattern of two gyres persisted until late August, when they gradually coalesced into a single "great whirl" with its northern edge at 9N (Brown *et al.*, 1980). One view of the two gyres in June 1979 is given in Figure 1. Evans and Brown (1981), re-examining infrared maps of sea surface temperature in the Somali Basin for earlier years after their observations in 1979, confirmed the indications of a low latitude gyre in the summer of 1976 and found evidence for one in 1978 as well, with 1977 indeterminate. Instead of being an anomaly, the two gyre circulation system had begun to appear as the normal state, at least until fairly late in the southwest monsoon.

In this paper, historical data are examined for evidence about the circulation pattern in the Somali Current system in earlier years. Was there a low latitude gyre? Did the current system develop, in other years, in the same way as it did in

1979? Despite all the inaccuracies in the surface currents, there are several years in which these questions can be answered fairly definitely.

2. Surface currents

Lists of historical surface currents were obtained from the British Meteorological Office, for the area bounded by 12N, 6S, 56E and the east coast of Africa. Monthly maps were plotted for May and June in each year from 1900 to 1973 when any data existed. These currents were sometimes derived from land fixes, but more usually from celestial navigation, being calculated between successive star sights, or between a noon sun position and stars. They are therefore usually averages over about 6 or 12 hours. For a ship's speed of 10 knots this means averaging spatially over 110 or 220 km, and proportionally more at higher speeds. The eddies seen in 1979 (Fig. 1) had diameters of approximately 500 km. Some smoothing of their features is to be expected in the historical maps. The data are unevenly distributed in space and time, depending on changes in use of shipping routes and the relative willingness of voluntary observers. The two decades from 1920 to 1939 are the best sampled.

Four examples of maps of May currents are given in Figure 2, chosen to illustrate the presence or absence of a low latitude gyre. In 1918 there probably was a low latitude (south of 5N) branch of the boundary current. It was certainly present in May 1929 and 1952, and there were fairly definite signs of recirculation in a gyre centered near the equator. The map for May 1959 suggests that the current did not turn off below 8 to 10N then. Summarizing the evidence from all the May maps, it appears that the boundary current certainly turned offshore south of 5N in 11 of the years sampled (1924, 1925, 1927, 1928, 1929, 1930, 1936, 1952, 1953, 1954, 1963). It probably did so in 7 more years (1918, 1919, 1922, 1926, 1931, 1933, 1966). It apparently did not in one year (1959). In other years the situation was indeterminate.

Figure 3 shows four of the June maps. Both gyres can be seen fairly clearly in the maps for 1927 and 1955. In June 1934 the low latitude gyre seemed probably absent, and 1941 was one of the few years with no indication of the northern branch turning offshore, though both gyres were probably present. In all, there were 25 years in which the current could certainly be seen turning offshore south of 5N sometime in June (1921, 1923-27, 1929-33, 1935, 1937-39, 1941, 1946, 1948, 1950, 1953-55, 1957, 1962, 1965). It probably did so in three more years (1917, 1936, 1963), and there were three years (1922, 1934, 1964) when it apparently did not. In 20 of the 25 "certain" years there was some evidence of recirculation (as in 1941, 1955). In four cases (e.g., 1927) rough estimates could be made of the dimensions and position of the eddy. They were similar to those in June 1979 (Fig. 1), 400 to 500 km diameter, centered between 1N and 1S.

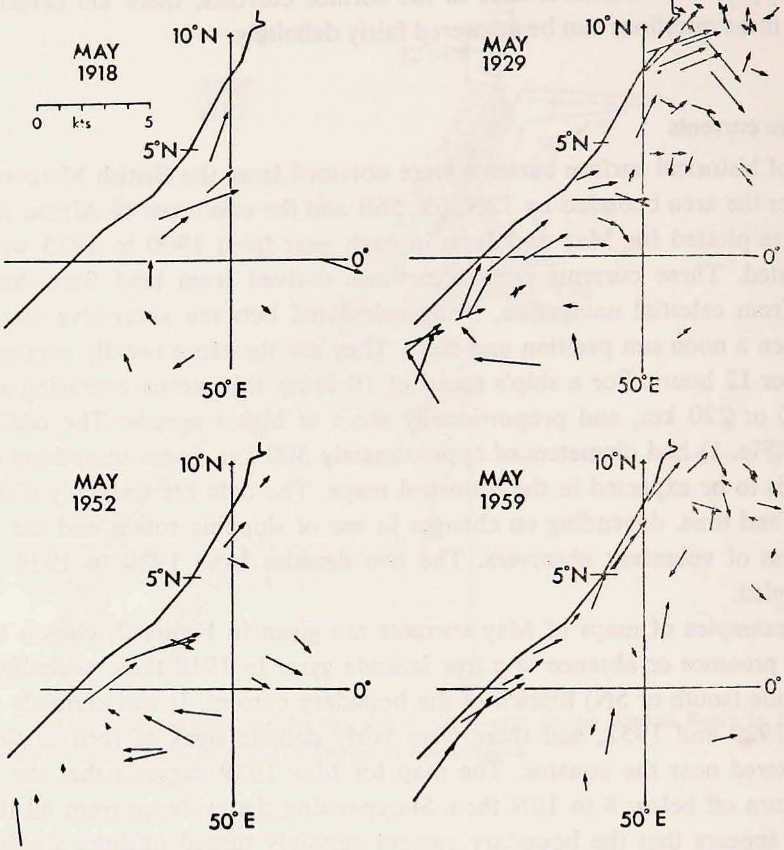

Figure 2. May surface currents for four selected years.

North of 5N, in May 1979 there was a weak northeastward boundary current and some evidence of offshore flow, which strengthened and became clearly organized as a gyre in mid June (Düing *et al.*, 1980). This strengthening of the northern branch of the boundary current can be recognized in several of the historical maps, though the data are often too noisy and sparse to reveal the complete gyre clearly. Taking an offshore component of current of at least 2 knots, between latitudes 7N and 10N, as evidence for the probable existence of a northern gyre, it can be said to have been present in 6 out of 38 adequately sampled years in May (1925, 1929, 1933, 1934, 1958, 1961), and in 47 out of 62 years in June (1900-15, 1919-33, 1935-39, 1953-56, 1959, 1960, 1963-67). Of the other 15 years in which the northern part of the boundary current could be seen clearly in June, though its offshore component was less than 2 knots, there were seven (1916, 1948, 1950-52, 1961, 1968) with some evidence of recirculation. In June 1941, as mentioned above, the northern gyre was probably present although the boundary current was

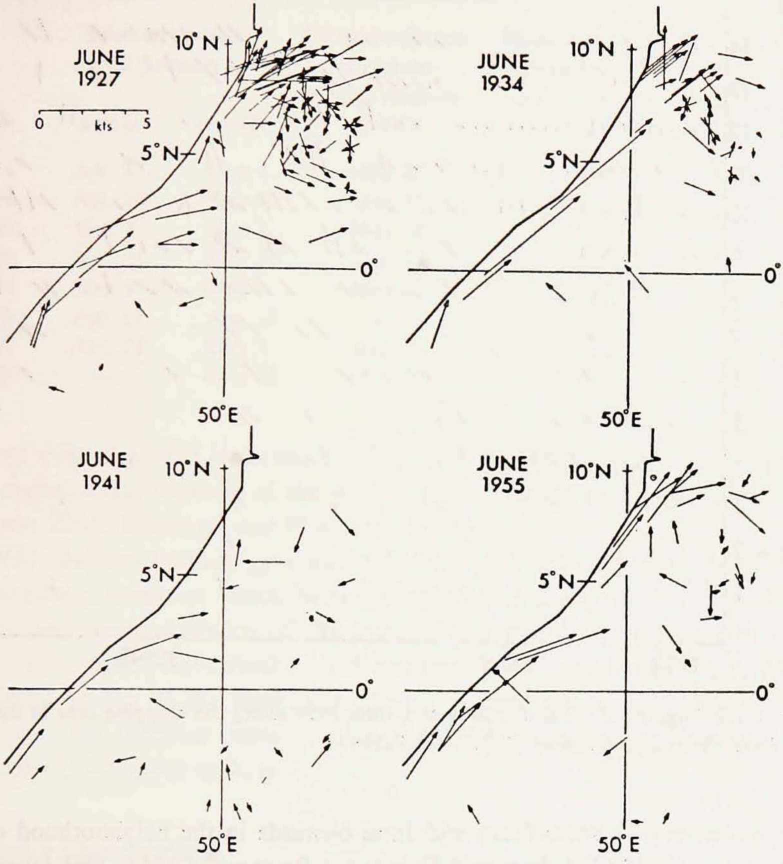

Figure 3. June surface currents for four selected years.

not sampled. The four best maps of the northern eddy in June (1925, 1928, 1929, 1933) show it centered near 7N, 53E, with a mean diameter of approximately 500 km, consistent with Findlay's (1866) description and what was seen there in June 1979.

3. Winds and currents

The stages of development of the Somali Current seen in May and June 1979 appeared to be related to changes in the local winds. The northward movement of the boundary current in the second week of May and its turning offshore at about 3N was preceded by the onset of winds from the south, blowing uniformly along the coast of Somalia with speeds of about 15 knots at the beginning of May. The appearance of the separate eddy between 5N and 10N in the second half of June was preceded by strong southwest winds off the northern part of the east coast of

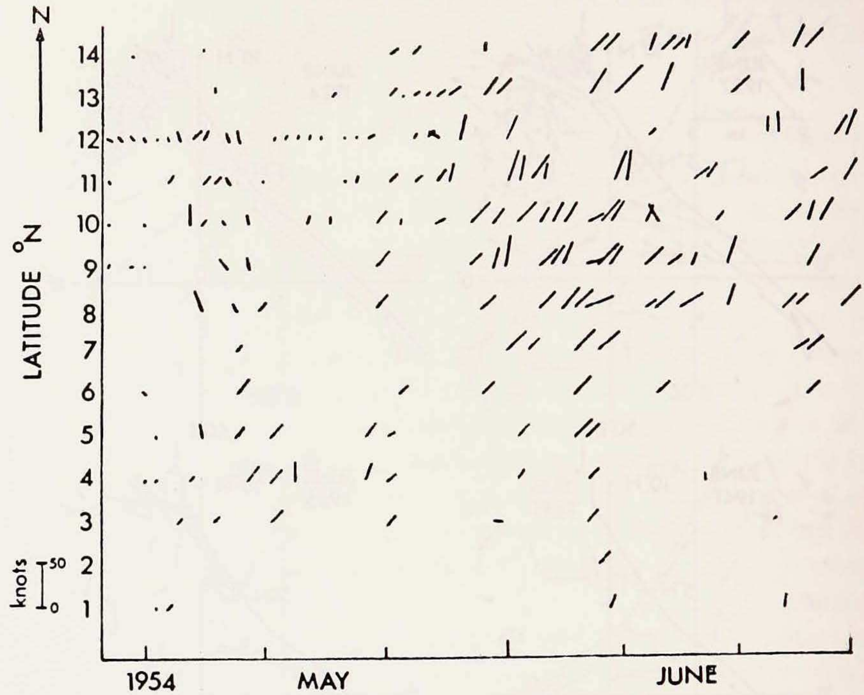

Figure 4. Stick diagram of winds for May and June 1954 along the shipping lane in the Somali Basin, from Fieux and Stommel (1977). See Table 1.

Somalia, exceeding 30 knots from mid June onwards in the neighborhood of 10N, 55E (Düing *et al.*, 1980, Schott and Fernandez-Partagas, 1981). This latter event, the appearance of the low level atmospheric jet off Somalia, is the one characterized by Fieux and Stommel (1977, 1978) as the monsoon onset in historical wind data from the shipping lanes intersecting at 12N, 54E. In their plots of winds for the shipping lane off Somalia as a function of time and latitude for the years 1934 to 1972, the monsoon onset at 12N is usually preceded by an alignment of weak southerly winds at lower latitudes, as in 1979. An example can be seen in Figure 4. In some years, useful comparisons can be made between the timing of these two events in the wind field and the earliest evidence for the existence of each branch of the boundary current. The results are given in Table 1.

For the northern branch, more years could have been included and the timing made more critical if the 2 knot criterion for the offshore component of current had been relaxed. Even so, these data suggest that the low latitude branch of the boundary current appeared within a week or two of the onset of local southerly winds, and that the northern gyre was well developed within two weeks of the appearance of strong southwesterly winds off northeastern Somalia. These results are

Table 1. Dates of appearance of wind and current features.

Year	Southerly winds off Somalia absent	Southerly winds off Somalia present	Earliest evidence of current turning offshore (2-4N)	Monsoon onset (from Fieux and Stommel, 1977)	Earliest evidence of current turning offshore (7-10N)
1934	Apr. 27	May 4	May 28	May 18-June 5	May 31
1936	Apr. 24	May 9	May 11	May 22 ± 1	June 4
1937	May 4	May 8	May 10	May 23 ± 3	June 6
1953	Apr. 16	May 10	May 19	May 3-June 5	June 19
1954	May 1	May 3	May 12	May 25 ± 1	June 7
1955	Apr. 11	Apr. 13	—	May 20 ± 1	June 18
1963	Apr. 28	May 5	May 6	May 24 ± 2	June 16
1966	—	May 12	May 20	May 24 ± 1	June 9

consistent with what was observed in 1979, and with some of the results of recent model studies of the response of the western Indian Ocean to changes of wind stress (Anderson, 1980; Delecluse and Philander, 1981).

In 1979, the low latitude gyre intensified but did not change its position much after the strong monsoon winds began. Similarly, in many of the historical maps for June there are indications of the low latitude gyre persisting *in situ* after the northern gyre started. Specifically, evidence could be found for the presence of the low latitude branch of the boundary current at least two weeks after the earliest indication of the northern branch, in 13 of the 19 years when both branches were clearly present sometime in June.

4. Sea surface temperatures

Lifting of the isotherms on the shoreward side of the boundary current, as it turns away from the coast, often leads to the formation of a wedge-shaped patch of cool surface water inshore of each separation region, which can be a useful indicator of the surface circulation pattern (Brown *et al.*, 1980). Historical sea surface temperature data are generally too sparse in individual months to define accurately the shapes of these regions of cool water. North of 5N it is difficult to distinguish between the cold area associated with separation of the boundary current and, for example, a poorly sampled strip of coastal upwelling. South of 5N, in several years there were indications of a cool patch near the coast, associated with current vectors turning offshore. Its presence in some other years allows the boundary current separation to be inferred although direct evidence from current observations was missing. Historical sea surface temperatures were plotted for each May and June in which data existed, in the area bounded by 5N, 2N, 50E and the coast. Temperature anomalies were considered significant if there were at least two observations in the same or neighboring one-degree squares, that were at least

2°C lower than the surrounding observations. No significant cold patches were found in May, but they were present in 21 years in June, of which nine (1906, 1907, 1912-14, 1947, 1949, 1959, 1968) were years in which there was no evidence from surface current observations about the existence of a low latitude branch of the boundary current. From the temperature evidence alone, its presence in those nine years sometime in June is considered probable.

5. Discussion

There was some evidence for a low latitude gyre (below 5N) in June in the Somali Current in 37 of the 63 years from 1906 to 1968. For the best sampled decades, 1920-1939, it was probably present in 16 of the 20 years and apparently not in two. There was some evidence for the northern gyre (5N-10N) in June in 55 of the 69 years 1900-1968. In 13 of the 19 years when both branches of the current were clearly present, they overlapped in time by at least 2 weeks. It seems fair to conclude that in most years there were two gyres in the Somali Current system for at least part of June.

It is reassuring to find that the pattern of current observed in June 1979 was not abnormal, and that (so far as one can tell from Table 1) the relative timing of developments in the winds and currents in May and June 1979 was similar to that in other years.

Indications of both branches of the boundary current can be seen in the monthly mean charts of currents in May and June in the K.N.M.I. atlas (1952) and in the 3-monthly mean chart for May, June and July in the Meteorological Office atlas (1939), which is not surprising since they are based on much of the same data as we have used here. Features in these multi-year mean charts are open to interpretation in various ways; however, without looking at the data in a nearly synoptic way, one cannot decide whether two gyres coexist or not.

Findlay's (1866) description of the northern gyre is remarkably clear and accurate. If he had been aware of the low latitude gyre, even as a transient feature, no doubt he would have mentioned it. He must have missed it because most of the current observations then available in the Somali Basin were along the coast and on the shipping route between the Gulf of Aden and Australia. It was not until the 1920's that an offshore route from the Gulf of Aden to Mombasa became popular, which sometimes cut across the low latitude gyre.

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