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Residual transport velocities during winter, within the Atlantis II deep area of the central Red Sea

Red sea
Atlantis II deep
Residual current
Winter

Mer Rouge
Fosse Atlantis II
Courant résiduel
Hiver

F. AHMAD, S.A.R. SULTAN and M.O. MOAMMAR

Faculty of Marine Science, King Abdulaziz University, PO Box 1540, Jeddah-21441, Saudi Arabia.

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ABSTRACT

The Atlantis II Deep is located at about 21.5° N within a deep trench which divides the Red Sea along the mid-axis. Data from the Atlantis II mooring, maintained during January-February 1978, provide valuable information about residual current distribution over the whole water column. The residual currents have speeds of 20 cm/s at the level of surface current meter, decreasing to 1.5 cm/s at about 250 m depth. The dominant direction over this depth level is southeast in January and changes to northeast in February. From 250 m down to the bottom the dominant direction is north-northwest and the residual speeds range between 1.5 and 3.0 cm/s at different depth levels. The weighted depth-mean residual current speed from surface to 250 m is about 7.7 cm/s, and in the deeper layer amounts to about 2.0 cm/s. These results suggest that the net transport in the deeper layer of the Atlantis II Deep is axial within the central trench in an almost north-northwest direction.

RÉSUMÉ

Courant résiduels en hiver dans la fosse Atlantis II de la mer Rouge.

La fosse Atlantis II, située vers 21,5° N, est une partie de la fosse axiale profonde qui divise la mer Rouge. Les données recueillies en janvier et février 1978 sur le mouillage Atlantis II précisent la répartition des courants résiduels sur toute la colonne d'eau. Les vitesses décroissent de 20 cm/s en surface à 1,5 cm/s vers 250 m de profondeur; dans cette couche superficielle le courant porte au sud-est en janvier et tourne au nord-est en février. Au-dessous de 250 m de profondeur, les eaux de fond s'écoulent vers le nord-nord-ouest à des vitesses résiduelles comprises entre 1,5 et 3,0 cm/s. La vitesse moyenne du courant résiduel est d'environ 7,7 cm/s entre la surface et 250 m de profondeur, et d'environ 2,0 cm/s dans les eaux profondes. Ces résultats suggèrent que le transport net au fond de la fosse Atlantis II est dirigé suivant l'axe de la fosse centrale, dans une direction proche du nord-nord-ouest.

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INTRODUCTION

The Red Sea (Fig. 1) is a flooded rift valley created by the separation of the Arabian and African crustral plates. It is some 1900 km in length with an average width of 220 km and narrows at the strait of Bab-el-Mandeb to about 27 km. The average depth is 524 m and a deep trench with a maximum recorded depth of 2920 m is continuous from 14° N to 28° N in the middle of the Red Sea. The Atlantis II Deep is located within this deep trench at about 21.5° N latitude. There is essentially no inflow to the Red Sea, except from the Gulf of Aden which penetrates the basin through the strait of Bab-el-Mandeb.

Due to the arid climate of the Red Sea, evaporation greatly exceeds precipitation. More recent estimates of evaporative heat flux are: 183 W/m^2 (Bunker and Goldsmith, 1979); 165 W/m^2 (Ahmad and Sultan, 1987); 168 ± 8 W/m^2 (Ahmad *et al.*, 1989).

Northward of about 20° N, the prevailing winds are mainly NNW all year round. Southward of about latitude 20° N, the winds are seasonally reversible monsoon winds. From May to September the winds blow from the same direction (NNW) as in the northern Red Sea. From October the winds start to change to SSE and maintain this direction until April.

Two main forces are involved in the general circulation: density differences and wind systems. The higher rate of evaporation, coupled with the lower surface temperatures towards the north, increases the density contrast and the resulting horizontal pressure gradient generates a surface inflow and a deep outflow through the strait of Bab-el-Mandeb. Maury (1955), Neumann and McGill (1962) and Phillips (1966) consider density contrast as the main driving force to control the circulation while Thompson (1939*a,b*), Siedler (1969) and Patzert (1974) consider wind as the primary factor for generating the flow. A two-layer winter flow pattern at Bab-el-Mandeb changes to a three-layer one in summer (surface outflow, a sub-surface inflow and a deep outflow) under the influence of the NNW winds.

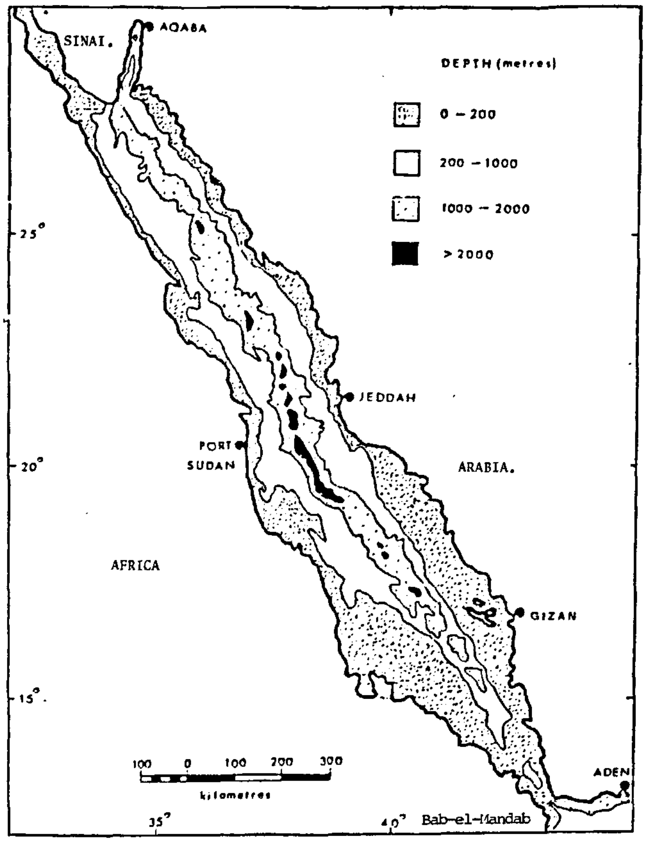

Figure 1

Map of the Red Sea showing the bathymetry

Direct current observations are only available at Bab-el-Mandeb and little is known about the regional currents, especially in the deep waters of the central Red Sea.

Vercelli (1927) describes the current observations of 15 days for the month of March 1924 in the strait of Bab-el-Mandeb. His measurements give a maximum mean surface inflow of 66 cm/s at the surface and a maximum mean sub-surface outflow of 68 cm/s at 150 m depth. From moored recording current-meter observations taken during November 1964, Siedler (1968) gives a maximum mean surface inflow of 80 cm/s and a maximum mean sub-surface outflow of 50 cm/s at 120 m depth. Patzert (1972) concluded from the ship's drift values that the monthly mean surface inflow into the Red Sea through the straits of Bab-el-Mandeb is 20 cm/s.

During winter the SSE winds of the southern Red Sea drive the surface water of the Gulf of Aden into the Red Sea. Between 19° N and 25° N the mean surface flow is NNW against the wind. North of 25° to 26° N a weak flow is to the south due to the NNW winds of the northern half of the Red Sea (Barlow, 1934; KNMI atlas, 1949; Boisvert, 1966). Bibik (1968) describes a large cyclonic eddy between 24° and 28° N from the winter hydrographic data. Boisvert (1966) also shows that from November to May a large cyclonic eddy dominates the circulation between 24° and 28° N.

During summer, the winds over the entire Red Sea are directed to the Gulf of Aden; consequently the surface currents are mainly in a SSE direction.

Barlow (1934) and KNMI (1949) show that currents have been recorded in all directions along the main shipping route. Maillard's (1971) analysis suggests that the currents during February 1963 were variable and generally across the sea. She hypothesized that the circulation at that time consisted of a series of large eddies, causing strong cross-currents.

Wassef *et al.* (1983) applied hydrodynamical equations to study the circulation and found the latter to be marked by gyres.

The aim of this paper is to describe the residual circulation within the Atlantis II Deep area of the central Red Sea.

DATA AND ITS ANALYSIS

Current-meter data from the Atlantis II Deep mooring (Fig. 2) were obtained from the Saudi-Sudanese Commission for the Exploitation of the Red Sea Resources collected during their Environmental Survey Programme

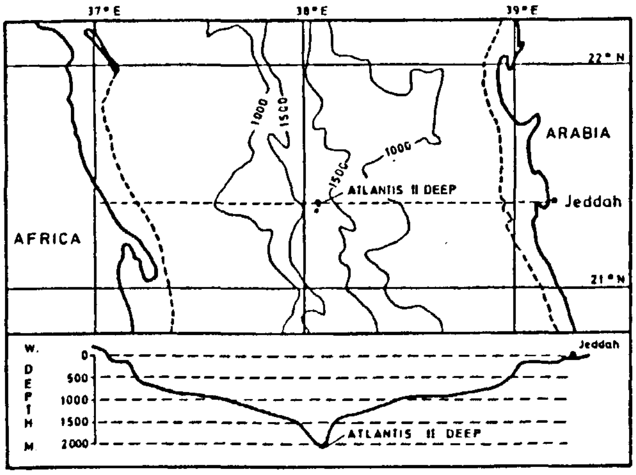

Figure 2

Location of the Atlantis II Deep. Average trench width at 1500 m is 16 km.

1977-78. The Atlantis II Deep area is located within the transition zone between the northern NW-wind regime and the monsoon regime which creates NNW-winds during summer and SSE winds during winter in the southern half of the Red Sea. The mooring line (approximately 21° 24'; 38° 06'), 1940 m deep, was equipped with 12 Aanderra current meters. Measurements-levels are 48, 105, 175, 255, 409, 603, 816, 1026, 1312, 1606, 1759 and 1906 m (Tab. 1). The Aanderra current meter records on to magnetic tapes in a binary code. The meters were set for a 20-minute recording interval and the duration of the record is from 23 January 1978 at 13.06 LT to 21 February 1978 at 07.06 LT (Local Time = GMT + 2). The I-shaped mooring line contained an acoustic release mechanism for recovery of the current meters.

The spectrum of the current-meter records can be divided into three bands:

1. The low-frequency band from 0-1 cycle/day.
2. The central band from 1-6 cycles/day.

Table 1

Average residual speeds and dominant direction at different depth levels of the Atlantis II Deeps of the Red Sea during Jan.-Feb. 1978. Total depth of water is 1940 m.

Depth in m	Speed cm/s	Dominant direction
48	20	SE in January and changes to NE in February
105	10	SE in January and changes to NE in February
175	4	SE in January and changes to NE in February
255	1.5	Variable in January and towards north in February
409	1.5	NNW all the time
603	1.0	NNW all the time
816	2.0	NNW all the time
1026	2.8	NNW all the time
1312	2.3	NNW all the time
1606	3.0	NNW all the time
1759	2.3	NNW all the time
1906	1.7	NNW all the time

1 Weighted depth-mean residual current from surface-250 m = 7.7 cm/s in SE and NE directions.

2 Weighted depth mean-residual current from 250-bottom = 2.0 cm/s in NNW direction.

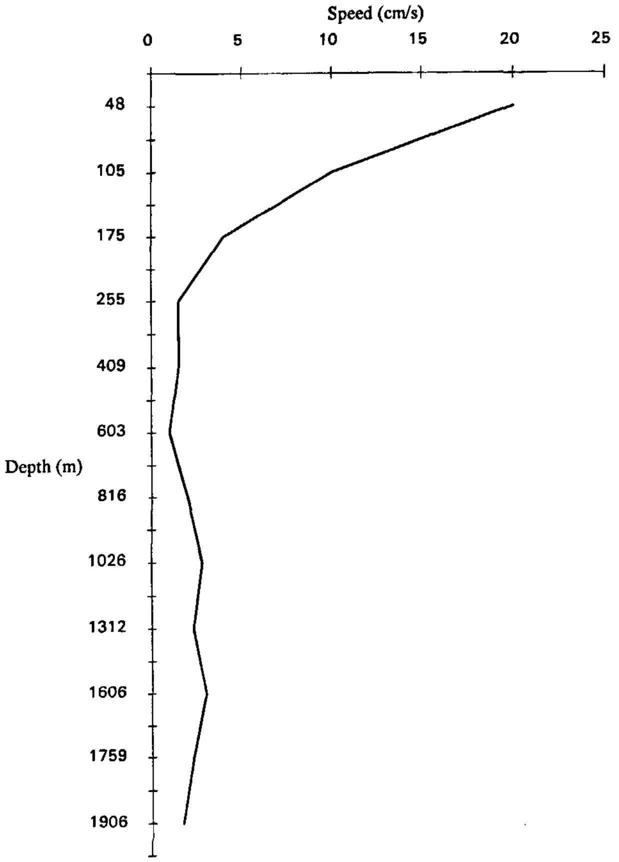

Figure 3

Variation of the average residual speed with depth.

3. The band containing frequencies higher than 6 cycles/day.

The low-frequency band contains the annual, seasonal and secular variations. The central band contains the diurnal and semi-diurnal tides, and the high-frequency band contains Seiches and other short-period oscillations.

To investigate residual currents, it is required that the high-frequency and the central band should be removed from the data. Different filters have been suggested to remove these bands from the smoothed data.

Godin (1972) recommends $\alpha_{24}\ \alpha_{25} / 24^2 - 25$ as the best filter to determine the residual values. The application of this filter requires 71 consecutive values. A sequence of means is first computed for 25 observations, then a series of means for 24 of these means and finally the mean of this last series, which gives the daily mean. An other simple filter is the arithmetic mean filter. It involves the mean of n consecutive observations of a time series: 25-hour smoothed observations in this case. The efficiency of the two filters was compared and it was concluded that the arithmetic mean filter provides a reliable estimate of the Eulerian residual drift through a moored current in the Red Sea. Therefore the records were analysed by applying a 25-hour mean filter.

From the hourly values of speed and direction, the u (towards the east) and v (towards the north) components were obtained as

$u = V \sin \theta$

$u = V \cos \theta$

An arithmetic mean filter was appto the u, v components. The resulting u, v values were then used to find speed and direction as

$V = u^2 + v^2$

$\theta = \tan^{-1} v/u$

θ is the angle with respect to x-axis.

The average speed of these residuals and the dominant direction is given in Table 1. The plot of the current speed with depth is given in Fig. 3. From the average residual at different depths, the weighted depth-mean residual current speeds from surface-250 m and for the deep waters were computed and are given at the foot of Table 1.

RESULTS AND DISCUSSION

The data from the current meters at 48, 105, 175 and 255 m levels show that the average residual speed at these levels is respectively 20, 10, 4 and 1.5 cm/s. The direction is southeast till the end of January and changes to northeast in February. At the levels of 409, 603, 816, 1026, 1312, 1606, 1759 and 1906 m the analysis of the current-meter data shows that the residual speed ranges from 1.5 to 3.0 cm/s at different levels and that the dominant direction is north-northwest. It seems reasonable to consider two layers: the upper layer from surface to 250 m, where the weighted depth-mean residual current speed is 7.7 cm/s in a SE direction in January and NE is February; and the lower layer from 250 m to the bottom, where the weighted depth-mean residual current is 2.0 cm/s in a NNW direction throughout the period of observations. It may be reasonable to consider that the currents within the uppermost 250 m are mainly wind-stress controlled. However this explanation does not fully account for a transport first to the SE and then to the NE.

One important reason for this current pattern would seem to be that the Atlantis II Deep area is located within the transition zone between the northern and southern wind regimes. Although the Atlantis II Deep area is controlled by the northern wind regime, there is a noticeable influence of the monsoon-driven currents which extend to 19° N. An alternate explanation for this current pattern may be the presence of a cyclonic gyre north of the central Red Sea which may change its lateral position from time to time so that it induces an easterly surface current within its southern part. The cyclonic gyre is reported by Maillard (1972), who calculated the geostrophic currents for the entire Red Sea.

There is no pronounced change in residual current speed below the uppermost 250 m. The average current velocity is 2.0 cm/s in the direction north-northwest. The results suggest that net transport is axial within the central trench and generally in a northerly direction.

Acknowledgements

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