ABSTRACT: The water circulation of the Egyptian Mediterranean waters was computed during winter and summer seasons using the dynamic method. The reference level was set at the 1000 db surface. The results showed that the surface circulation is dominated by the Atlantic water inflow along the North African coast and by two major gyres, the Mersa Matruh anticyclonic gyre and El-Arish cyclonic gyre. The results showed a seasonal reversal of El-Arish gyre, being cyclonic in winter and anticyclonic in summer. El-Arish gyre had not been previously measured. The geostrophic current velocity at the edges of the Mersa Matruh gyre varied between 12.5 and 29.1 cm/sec in winter and between 6.5 and 13.1 cm/sec in summer. The current velocity reached its maximum values (>40cm/sec) at El-Arish gyre. The current velocity at the two gyres decreased with increasing depth. The North African Current affects the surface waters down to a depth of 100 m, and that its mean velocity varies between 6 and 38 cm/sec.

KEY WORDS: Water circulation - current velocity - Mediterranean Sea - Egypt.

INTRODUCTION

Direct current measurements in the southeastern Mediterranean off the Egyptian coast were very scarce. A few current measurements using an Ekman current-meter were made in 1969 between Port-Said and Abu Qir Bay (Hassan, 1969). Gerges (1981) studied the monthly patterns of surface currents obtained by averaging all current measurements carried out in each one-degree square along the Egyptian coast over a period of 50 years, up to the early Seventies.

The scarcity of direct current measurements for the Egyptian coast has led to the use of indirect methods; by constructing T-S diagrams, and sections of horizontal and vertical distributions of some physical and chemical properties of seawater such as salinity, temperature and oxygen (Halim et al., 1967; Hassan, 1969; Morcos and Hassan, 1976; Saad, 1984; Abdel-Moati and Said, 1987 and Said and Karam, 1990), and by the dynamic method (Sharaf El-Din, 1976; Sharaf El-Din and Karam, 1976). From the temperature and salinity data taken in front of the Nile Delta during the period 1948-1971, the seasonal dynamic topography for that area was studied by Karam (1977).

Little is known about the circulation pattern of the Egyptian Mediterranean waters. The aim of the present work is to reconstruct the water circulation maps using the more recent observations, compare them with the previous works and define the more accurate details of the current system during the winter and summer seasons on the Egyptian Mediterranean shelf.
MATERIALS AND METHODS

Selected oceanographic data used in the present work are from several expeditions carried out by Egypt and different countries for the last 27 years (1959-1986). Water temperature and salinity data have been taken from 162 hydrographic stations in winter, and from 152 stations in summer. Winter data were collected during the period from January to March, while summer data were collected from July to September. Vertically unstable station data have been corrected for temperature and/or salinity. Only few observations have been rejected because of poor quality, due perhaps to personal instrumental and/or location errors.

The average values of temperature and salinity of these data were computed, using the optimum interpolation of the correlation algorithm, for stations distributed in a regular grid half degree latitude by half degree longitude for the winter and summer seasons as shown in Fig. 1. The optimum selection of the grid size have been chosen according to Said (1984a).

![Fig. 1(A). Egyptian Mediterranean coast, and the regular net at which the average temperature and salinity were calculated for the winter and summer seasons; (B) Bathymetry of the Egyptian Mediterranean coast.](image-url)
The computed averages of water temperature and salinity were used for computing the dynamic height. The reference level was set at the 1000 db surface. In the shallow parts of the study area where the depths were less than the depth of the reference level, Groen's (1948) method was applied.

The dynamic height anomaly differences between stations were substituted in the Sandstrom and Halland-Hansen (1903) formula to compute the geostrophic currents. The current components are then averaged to obtain the current speed and direction at the centre of each grid.

RESULTS AND DISCUSSION

Charts of surface circulation constructed for the winter and summer seasons are shown in Figs. 2A and B. The surface circulation is dominated by the Atlantic water inflow along the North African coast and by the Mersa Matruh anticyclonic gyre in the western part of the Egyptian coast. This gyre has been called the Egyptian anticyclonic gyre by Said (1984b and 1990), the Egypt high by Brenner (1989) and Mersa Matruh by Ozsoy et al. (1989).
In the eastern side of the Egyptian coast off El-Arish city, the circulation is cyclonic in winter. This circulation exhibits a strong winter to summer variability, reversing from cyclonic to anticyclonic (Figs. 2A and B). In the scientific literature there is no evidence of the existence of such a gyre. Consequently, we will call it El-Arish gyre. This gyre is more intense in winter and weaker in summer. This may be due to the circulation of the atmospheric cyclones over the Eastern Mediterranean that are present mainly in the winter. To the east of El-Arish gyre, the southern extents of the Shikmona gyre is observed in the both seasons. This gyre was discussed in details in POEM-I-85 and POEM-II-86 by Ozsoy et al. (1989).

The geostrophic current velocity at the edges of Mersa Matruh gyre varies between 12.5 and 29.1 cm/sec in winter, and between 6.5 and 13.1 cm/sec in summer (Figs. 4A and B). The current velocity reaches its maximum values (>40 cm/sec) at El-Arish gyre in winter. The current velocity at the two gyres decreases with increasing depth.

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Fig 3. Surface geostrophic current along the Egyptian Mediterranean coast during: (A) winter and (B) summer.

The dynamic chart for the surface (Fig. 2A) during winter indicates the existence of a current carrying water from west to east. This inflow of water is deflected to the
Fig. 4. Dynamic relief (dyn. m) at the 50 db surface during: (A) winter and (B) summer.

Fig. 5. Geostrophic current pattern at the 50 db surface along the Egyptian Mediterranean coast during: (A) winter and (B) summer.
Fig. 6. Dynamic relief (dyn. m) at the 100 db surface during: (A) winter and (B) summer.

Fig. 7. Geostrophic current pattern at the 100 db surface along the Egyptian Mediterranean coast during: (A) winter and (B) summer.
Fig. 8. Dynamic relief (dyn. m) at the 250 db surface during: (A) winter and (B) summer.

Fig. 9. Geostrophic current pattern at the 250 db surface along the Egyptian Mediterranean coast during: (A) winter and (B) summer.
southeastern direction in front of the Nile Delta. In summer, the inflow from the west flows eastward parallel to the coast and bifurcates into two parts. The great part of this flow is directed to the east and a minor part is carried to the southeast and bends southward to the coast at approximately the 30°E longitude. This surface water flows into the Mediterranean from the Atlantic through the strait of Gibraltar with a salinity value of 36.25 ppt. Salinity increases to reach 37.25 ppt in the Strait of Sicily and to values higher than 38.50 ppt in the Levantine Sea forming the Modified Atlantic Water. The currents west to east path across the Mediterranean can be tracked by a subsurface salinity minimum (Lacombe and Tchernia, 1960), the signature of its Atlantic origin.

Another flow of water entering the eastern part of the area from the Levantine Sea, originates a current of velocity range 10-25 cm/sec moving to the west in winter and reverse its direction to the east in summer. (Figs. 2A and B). This flow may be incoming from the Cyprus high or from the Levantine cyclonic gyre.

Dynamic topography for the upper 50 and 100 m levels (Figs.4A-7B) reveals the same general pattern of those observed at the surface for the winter and summer seasons. Except in summer, El-Arish gyre is completely absent while the Mersa Matruh gyre at 100 m level splits into two centres (Fig.6B).

At the deeper levels (Figs.8A-9B), small eddies appear within the major gyres as well as between them. The Mersa Matruh gyre is intensified and split into multiple centres. The eddy centres are shifted horizontally with depth. These features were also observed and discussed by Ozsoy et al. (1989). At the 500 m level, the Mersa Matruh gyre could be observed during the both seasons, while El-Arish gyre could still be identified only in winter and consists of two small gyres.

Winter geostrophic current charts for the 250 and 500 m levels indicate that, the Levantine Intermediate Water is transported from the Levantine Sea to the eastern coast of Egypt and flows away from the continental shelf to the open sea in the northwest direction. The current velocity of the intermediate water reaches 5-12 cm/sec.

The general features of the circulation of the intermediate layers on the Egyptian Mediterranean shelf coincide with the movements of waters described by Said and Karam (1990). In their work they concluded that; "In winter, a low-salinity tongue extends from the open sea in the north to the eastern coast of Egypt, in which low-salinity water (<38.95 ppt) is carried southward and reaches the Egyptian coast with its salinity increasing to about 39.10 ppt. This water is combined with the intermediate water formed on the Egyptian shelf from the three regions of this formation. These saline waters flow away from the continental shelf to the open sea in the northwest direction" with values as low as 38.95 ppt.

Comparing Sharaf El-Din and Karam's (1976) and Karam's (1977) maps with the results of the present work one can find that the two major gyres (Mersa Matruh and El-Arish) were absent in the previous works. These gyres are clearly observed in the present work. This is due to the significant increase in the number of the hydrographic stations which were carried out in study area during recent years, and the method used for obtaining the average data in a regular net for the study area.
CONCLUSION

The oceanographic data used in the present study were selected from several expeditions carried out by Egypt and different countries for the last 27 years (1959-1986). The average values of temperature and salinity of these data were computed, using the optimum interpolation of the correlation algorithm, for stations distributed in a regular grid of half degree latitude by half degree longitude for the separate winter and summer seasons.

The surface circulation of the Egyptian Mediterranean waters is dominated by the Atlantic water inflow along the North African Coast, and by Mersa Matruh anticyclonic gyre. A new cyclonic gyre called El-Arish gyre was observed in the eastern part of the study area. The results showed a seasonal reversal circulation of El-Arish gyre, being cyclonic in winter and anticyclonic in summer. At deeper levels (250 and 500m), small eddies appear within the major gyres as well as between them. The Mersa Matruh gyre is intensified and split into multiple centres. The eddy centres are shifted horizontally with depth. The geostrophic current velocity at the edges of Mersa Matruh gyre varied between 12.5 and 29.1 cm/sec in winter and between 6.5 and 13.1 cm/sec in summer. The current velocity reached its maximum values (>40 cm/sec) at El-Arish gyre. The current velocity at the two gyres decreased with increasing depth. The North African Current affects the surface waters down to a depth of 100 m, and that its mean velocity varies between 6 and 38 cm/sec.

More observations are needed to define the year to year variabilities of these gyres, and their responses to atmospheric forcing.

REFERENCES


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