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MODELING THE SEASONAL VARIABILITY OF DENSITY CURRENT IN ABU-QIR BAY

By

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Key words: Abu-Qir Bay – Numerical modeling – hydrodynamical model water circulation – density current – thermohaline circulation.

ABSTRACT

Abu-Qir Bay is a shallow semicircular basin lying between Abu-Qir headland and Rosetta headland. It has a maximum depth of about 15m, and an area of about 500 km^2.

Due to the land runoff of fresh water from Rosetta mouth and brackish water from Lake Edku, the water salinity in Abu Qir Bay varies with a wide range. This wide range of salinity variation causes a significant variation in water density. Therefore density currents take a considerable contribution of water circulation in the Bay.

Three dimensional hydro-dynamical model was used to simulate the thermohaline circulation in Abu-Qir Bay during the different seasons with a horizontal resolution of about 0.5 minute.

The simulation results showed that the density (thermohaline) circulation in the Bay is very complicated. A lot of rotating motions (eddies) can be detected during different seasons. The main features of the surface circulation during ***winter*** *are the extensive anticlockwise eddy in front of Rosetta mouth due to the huge amount of fresh water discharged during this season.*

During ***spring*** *the general trend of surface circulation is dominated by the clockwise direction. The brackish water discharged from Lake Edku directed northwestward to the open sea in the western* *part of the bay while, the Mediterranean water inters the bay in the central and northern parts. The maximum current speed of about 13 cm/sec can be detected in the western part of the bay in front of El-Maadiya outlet.*

In ***summer****, the general pattern of the surface circulation is characterized by the seaward flow in front of El-Maadiya outlet and the shoreward flow in the central and western parts of the Bay. This circulation pattern leads to the accumulation of less saline water in the eastern and western parts of the Bay.*

During ***autumn****, the shoreward flow off Maadiya outlets divided the brackish water discharged from Lake Edku and El-Tabia mamping Station into two parts. The first part flows in the northwest direction causing an accumulated of less saline water along the southwestern coasts. The second one flows northeastward making a clockwise gyre in the central part of the bay where the less saline water accumulated inside the Bay*

INTRODUCTION

Due to the land runoff of fresh water from Rosetta mouth and brackish water from Lake Edku, Abu Qir Bay waters shows a wide range of salinity variation. Such variation in salinity values causes a significant variation in water density. Therefore density currents take a considerable contribution of water circulation in the Bay.

Hydrographical conditions and water masses in Abu-Qir Bay and its effect in the circulation pattern of the Bay were studied by many authors. El-Sharkawy and Sharaf El-Din (1974), Said (1979) and Sharaf El-Din *et al.* (1980) studied the hydrographic structure and circulation pattern of Abu-Qir Bay. The exchange of water masses between Lake Edku and the Bay on the basis of salinity distribution was studied by Dowidar *et al.* (1976) and Mohamed (1981). Circulation, water masses and pollutant transport in Abu-Qir Bay were studied by El-Gindy (1988), and El-Gindy *et al.* (1991). The hydrographic structure and heat budget of Abu-Qir Bay were studied by Radwan (1996). Alam El-Din (2000) studied the wind driven circulation and its effect in pollutant transport in Abu-Qir Bay using a three dimensional hydrodynamical model.

In the present work the density current (thermohaline circulation) in Abu-Qir Bay and its variability with different seasonal conditions were simulated using a three dimensional hydro-dynamical model. Historical data from different hydrographical observations were used to initialize the model. The average monthly water discharge from different land base sources were used to simulate the effect of discharge on the water circulation in the Bay.

AREA OF STUDY

Abu-Qir Bay is a semi-circular basin, which lies at about 35 km northeast of Alexandria city, between longitude 30° 4′ and 30° 20′ East and latitude 31° 16′ and 31° 28′ North, (Fig. 1). It has a maximum depth of about 15 m, and an area of about 500 km^2. The bay has a shoreline length of about 50 km. The depth ranging from less than one meter along the coast, increasing gradually away from the shore to reach a maximum depth of about 15 m. The 20 meters contour is found mostly at about 40 km far from the coast. The Bay is bordered from the

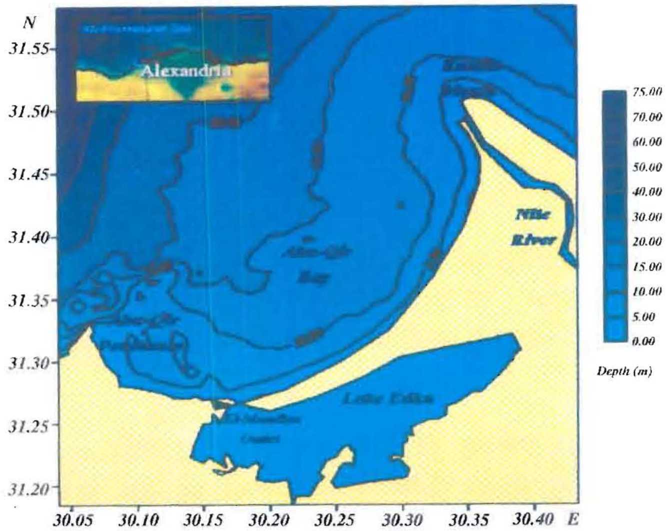


Fig. 1: Location and bathymetric map of Abu-Qir Bay.

West by Abu-Qir headland and from the East by Rosetta Peninsula where the Rosetta branch of the River Nile flows into the sea (Nasr, *et al*.1996).

HYDROGRAPHICAL CONDITIONS OF ABU-QIR BAY.

Since Abu-Qir Bay is a semi-enclosed basin, many of its hydrological regimes are related to its geographical position and land base sources effluents.

a- Historical Hydropgrahical Surveys

The first hydrographic survey in Abu Qir Bay has been done during the period 1969-1970 by the R/V Faras El-Bahr, belonging to Alexandria Institute of Oceanography and Fisheries. In this survey, forty-three samples were collected from the Bay in May 1969. In March and August 1970, fourteen hydrographic stations were carried out in the same region.

Eight hydrographic cruises were carried out in Abu-Qir Bay, covering 23 stations each time during the period from January 1977 to February 1978.

During the period 1983-1984 a hydrographic survey and current measurements were taken in Abu Qir Bay from the coast to 15 m depth. The hydrographic stations were located in front of Lake Edku Outlet (Bogaz El-Maadiya) and Rosetta mouth of the River Nile (El Gindy *et al*., 1984).

In 1990, a complete hydrographic survey was carried out during a one-year program. Twenty hydrographic stations used to measure temperature and salinity at surface and near bottom through six cruises over the year (Radwan, 1996).

b- Data Processesing

The latest hydrographic survey of 1990 (Radwan, 1996) was used as the main data set to feed the hydro-dynamical model by the initial fields for temperature and salinity. To fill the area outside the Bay with the required hydrographic data, the MED4 seasonal climatology dataset (A grided dataset provided by the Mediterranean Ocean Data Base-MODB) for temperature, salinity and velocity are used. In addition all temperature and salinity data available in front of Abu-Qir Bay up to 1995 were used to adjust the initial fields. All the compiled data have been interpolated to the model grid to feed the hydro-dynamical model with the initial fields of temperature and salinity.

NUMERICAL SIMULATION

1- Model Setup

The numerical simulation was preformed by the Princeton Ocean Model (POM) developed at Princeton University (Blumberg and Mellor, 1987). The POM model is a three-dimensional primitive equations, time dependent, sigma coordinate, free surface, coastal ocean circulation model.

The simulation domain has dimensions of about 32 km x 37 km. Horizontal resolution of about 0.5 minute is used (about 800 m in X-direction and 925 m in Y-direction) with a number of grid points of about 40 x 40 and 8 vertical sigma levels. The bottom topography is taken from 1:100,000 bathymetric map.

To simulate the density currents (thermohaline circulation) the model was started after reaching the stability conditions, with the initial fields of temperature and salinity. In the present study the wind stress was ignored (i.e. Surface momentum fluxes are set to zero).

The initial velocities were assumed to be zero. Free radiation condition was used for the normal velocity at the open boundaries while the normal and tangential velocities were set to zero at the coastline everywhere. The model runs in prognostic mode with external and internal mode time steps (ΔTE & ΔTI) of 2 sec and 150 sec respectively.

2- Initial Fields

Historical data from different hydrographical observations were completed by MODB Med4 data set and interpolated to the model grid using bilinear interpoliation.

a- Horizontal distribution of water temperature:

In Abu-Qir Bay, seasonal variations of water temperature are related to the seasonal climate variations. Fig. 2 shows the horizontal distribution of surface temperature during different seasons.

In winter (January), the distribution indicates that the surface water temperature varies between 15.50°C and 16.90°C; the minimum temperature was observed at the mouth of Rosetta while the maximum was observed at the central part of the Bay (Fig 2-a).

During spring (May), the general trend is the decrease of surface temperature in a direction away from the coast of the Bay, while the central part has a temperature colder than that observed in the eastern and western parts (Fig 2-b).

In summer (July), the surface isotherms run almost parallel to the coastline in the eastern part of the Bay, ranging between (29.5℃) near the coast and

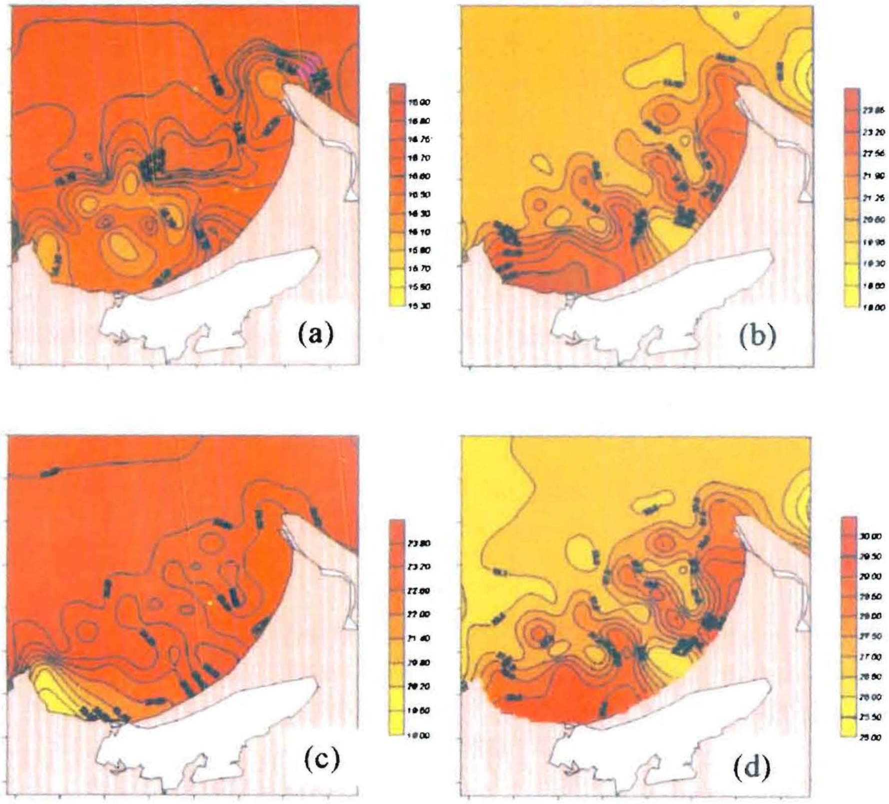


Fig. 2: Horizontal distribution of surface temperature at different seasons
a. January. b. May. c. July. d. November.

(27.0°C) outside the Bay. In general, the water temperature at surface decreases seawards (Fig 2-c).

During autumn (November), the water temperature varies between (20.20°C) near Abu-Qir head land and (23.05°C) in the vicinity of Rosetta mouth (Fig 2-d).

b- Horizontal distribution of salinity:

The Bay shows wide range variability in salinity, from brackish water near the outfalls to the Mediterranean water outside the bay.

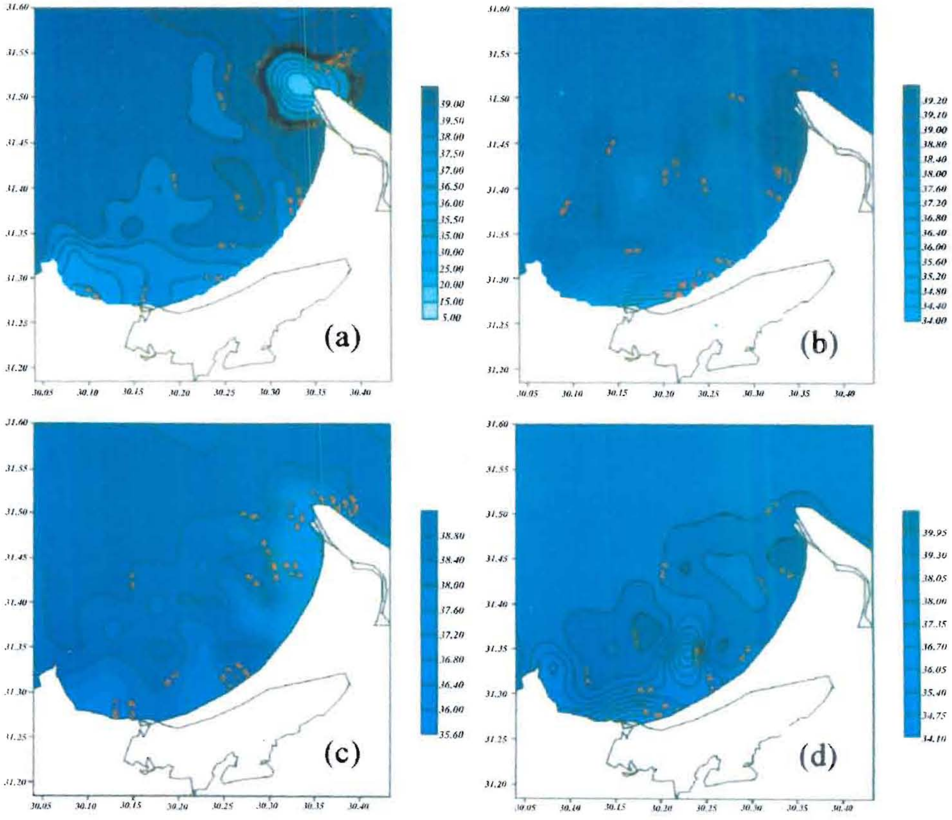


Fig.3: Horizontal distribution of surface salinity at different seasons
a. January. b. May. c. July. d. November.

During winter, the fresh water discharged from Rosetta mouth affects the salinity distribution in the Bay. In January, the minimum surface salinity (6.422 PSU) is observed at Rosetta mouth. Less saline water (37.50 PSU) is observed in the western part of the Bay (Fig 3-a), because of the brackish water discharging from Lake Edku through El-Maadiya outlet and the wastewater from El Tapia Pumping Station (TPS).

During spring, the amount of fresh water discharged from Rosetta mouth decreases, while the brackish water discharged from Lake Edku through El-Maadiya outlet influences the distribution of surface salinity in the Bay. In May, the surface salinity reaches its minimum value (34.9 PSU) near El-Maadiya outlet and a maximum one (39.20 PSU) south of Rosetta Mouth (Fig 3-b).

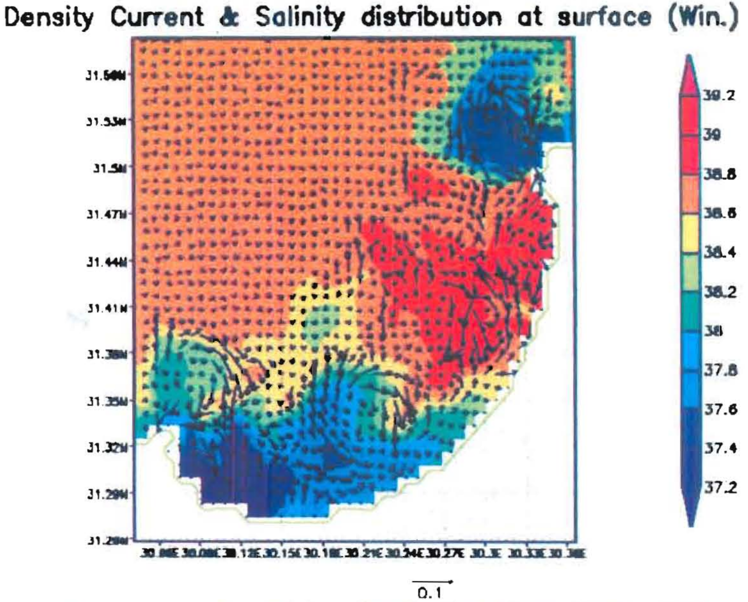
During summer, the salinity distribution was clearly affected by the water discharged from Rosetta mouth, the brackish water from Lake Edku and the wastewater from Tabia Pumping Station. In July, the surface salinity varies between (36.26 PSU) near Rosetta mouth and (38.616 PSU) for the offshore water (Fig 3-c).

During autumn, the salinity distribution in the Bay is very complicated. The coastal area is influenced by the brackish water from Lake Edku and TPS. Generally, the water salinity increases to its maximum value throughout the year during November (39.90 PSU).

SIMULATION RESULTS

The model runs four times starting from Jan., May, Jul. and Nov. conditions to represent different seasons. The output patterns of density (thermohaline) circulation at surface and near the bottom, after 240 hrs POM simulation, are presented in figs (4-7) for the different seasons.

In general, the density (thermohaline) circulation is very complicated. A lot of rotating motion has been detected in the low and high salinity regions. The surface current speed during different seasons is ranging between 10 and 15 cm/sec while, the near bottom circulation is rarely exceeds 8 cm/sec, as described below.


Density Current & Salinity distribution at surface (Win.)

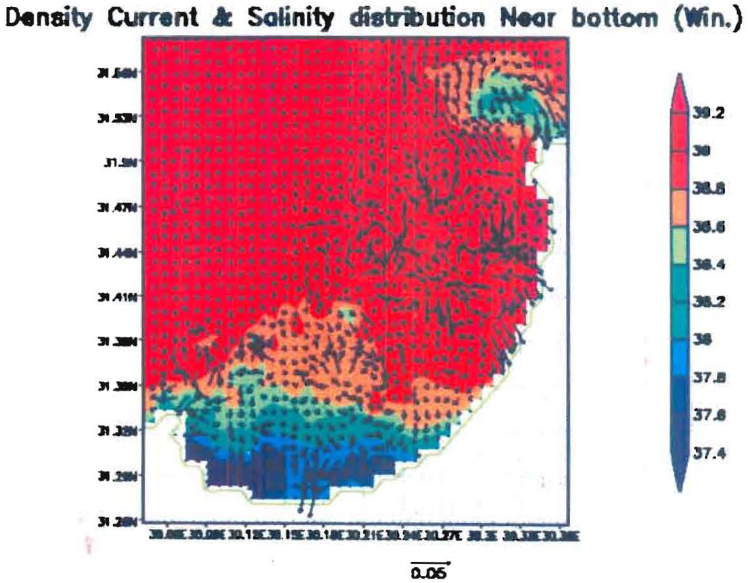
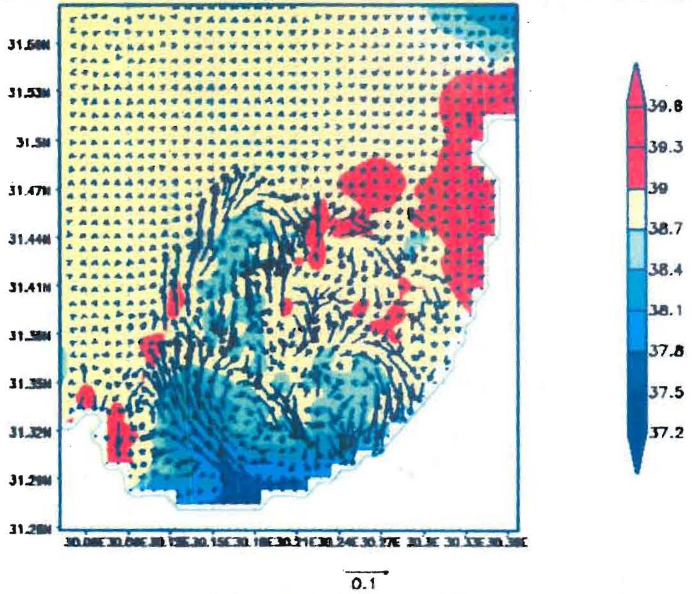

Density Current & Salinity distribution Near bottom (Win.)

Fig. 4: Density (thermohaline) circulation at surface and near bottom during winter after 240 hrs POM simulation.

Density Current & Salinity distribution at surface (Spr.)



Density Current & Salinity distribution Near bottom (Spr.)

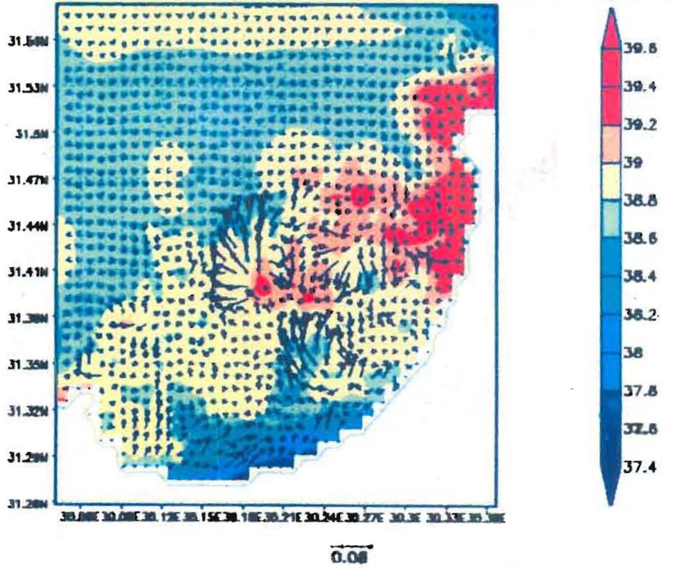
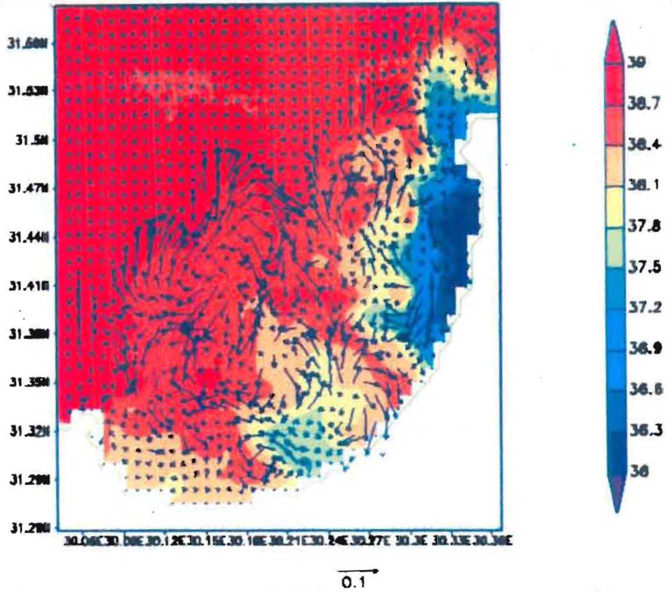


Fig. 5: Density (thermohaline) circulation at surface and near bottom during spring after 240 hrs POM simulation.

Density Current & Salinity distribution at surface (Sum.)



Density Current & Salinity distribution Near bottom (Sum.)

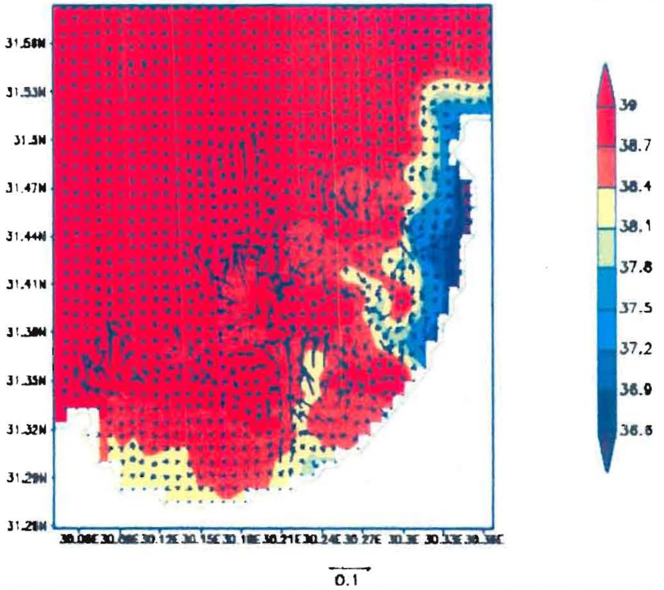
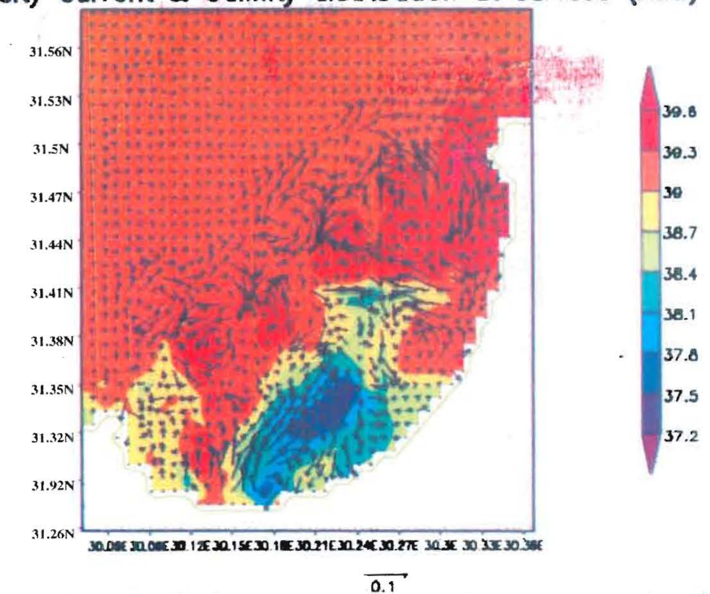
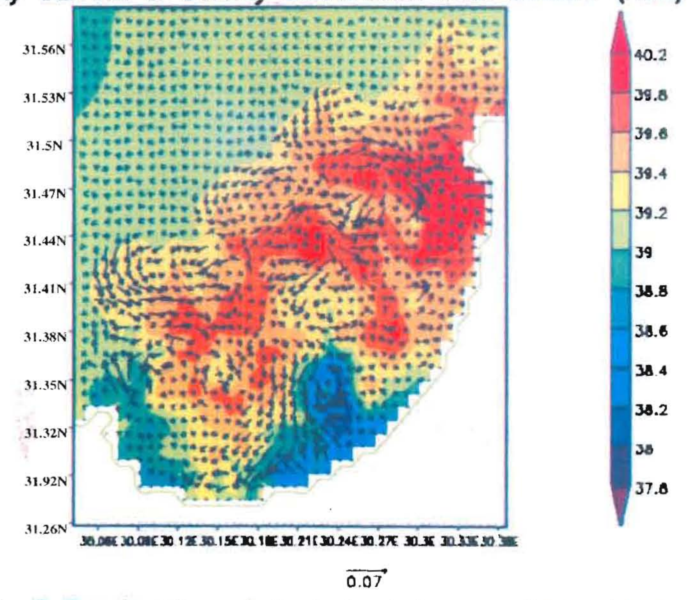


Fig. 6: Density (thermohaline) circulation at surface and near bottom during summer after 240 hrs POM simulation.



Density Current & Salinity distribution at surface (Aut.)



Density Current & Salinity distribution Near bottom (Aut.)

Fig. 7: Density (thermohaline) circulation at surface and near bottom during autumn after 240 hrs POM simulation.

a- In Winter

During winter, the density circulation is dominated with sharp gradient in salinity in front of Rosetta Mouth due to the huge amount of fresh water discharged there during this season. There is also a remarkable gradient in salinity in the western part of the Bay due to outflow of brackish water from Lake Edku.

Fig. (4-a & b) gives the density currents and salinity distributions at surface and near bottom after 240 hrs of numerical simulation. The figure shows that the mean features of the surface circulation are the extensive anticlockwise eddy in front of Rosetta mouth and the clockwise one in front of Abu Qir headland. Inside the Bay, a clockwise motion is clearly observed in the central and eastern parts, while in the western part an anticlockwise eddy can be noticed. Two convergence regions in the eastern and southern parts of the bay can be detected. At the surface there is a clear evidence of seaward flow in the central region and inshore currents in the northern part of the Bay.

The near bottom circulation shows mostly opposite patterns to that observed at surface, where The Rosetta eddy becomes in the clockwise direction. The seaward flow occurs in the northern part while inshore one occurs in the central part.

b- In Spring

During this season, the outflow of brackish water from Lake Edku causes remarkable decrease of salinity, therefore the density gradient increase rapidly in the southern part of the Bay. The general trend of surface circulation is found to be in the clockwise direction. The brackish water discharged from Lake Edku is directed northwestward to the open sea in the western part of the Bay. The Mediterranean water enters the Bay in the central and northern parts to replace the outflow water in the western part. The maximum current speed of about 13 cm/sec can be detected in the western part of the bay in front of El-Maadiya outlet (Fig 5-a).

The water near the bottom has a tendency to rotate anticlockwisely in reverse manner to that occurred at the surface, where the seaward flow dominates the central part of the Bay. In the eastern and western parts the shoreward flow can be noticed in the near bottom circulation (Fig 5-b).

b- In Summer

The general pattern of density circulation at surface is the clockwise rotation in the central part of the Bay. In front of Rosetta mouth a divergence region can be detected. In the western part of the Bay an anticlockwise rotation can be noticed. The seaward flow can be clearly detected in front of El-Maadiya outlet and in the eastern part of the Bay, while the inshore flow takes place in the central and western parts of the Bay. This circulation pattern leads to the accumulation of less saline water in the eastern and western parts of the Bay (Fig 6-a).

The main feature of the near bottom circulation is the seaward flow in the central part of the Bay as shown in fig (6-b).

c- In Autumn

The maximum rate of water discharge over the year, from El-Maadyia outlet and El-Tabia Pumping Station, occurs during the autumn and causing an intensive gradient in water salinity in the southwestern area of the Bay. On the other hand, the water discharge from Rosetta mouth is nearly stopped.

The numerical simulation of density (thermohaline) circulation gives an explanation for the abnormal and complicated distribution of salinity during this season. The shoreward flow off Maadiya outlets divided the brackish water discharged from Lake Edku and El-Tabia Pumping Station into two parts. The first part flows in the northwest direction causing an accumulation of less saline water along the southwestern coasts. The second one flows northeastward making a clockwise rotation in the central part of the Bay where the less saline water is accumulated inside the Bay (Fig. 7-a).

The shoreward flow dominates the near bottom circulation with maximum values in the central part which is the deepest part of the Bay. Many eddies can be noticed in the near bottom circulation around the minimum and maximum salinity regions (Fig 7-b).

VALIDATION AND DISCUSSIONS

The direct current measurements in Abu-Qir Bay were scare. Few current measurements using Ekman current-meter were carried out in front of Abu-Qir Bay during 1969. According to (Hassan, 1969) and (Morcos and Hassan, 1973) the measurements showed a northeasterly current with velocity range between 15 cm/s and 17 cm/s out side the Bay. The simulation results showed the same pattern with small velocities. The difference of magnitude between simulated and observed velocities is due to the effect of the prevailing NW wind.

According to (Gerges and Salama, 1979) the current measurements in Abu-Qir Bay indicated a clockwise circulation in the eastern two thirds of the Bay, while in the western part a weaker anticlockwise current was observed. This conclusion showed a high agreement between the current measurements and the general pattern of the simulation results at surface figs (4-7-a).

El-Gindy et. al. (1984), and El-Gindy *et al.* (1991), using the current measurements were taken in front of Lake Edku Outlet (Bogaz El-Maadiya) and Rosetta mouth of the River Nile during the period 1983-1984, concluded that: the surface current in front of El-Maadiya outlet, is a quite complex pattern. The surface current pattern exhibits a line of divergence extending S-N with an anticlockwise eddy in front of Rosetta headland At 5 meter depth, North of Rosetta and in front of El-Maadiya outlet, the offshore current is dominating.

From the comparison between the simulation results and these observations we can conclude that: all features noticed by of El-Gindy *et al.* (1984), and El-Gindy *et al.* (1991) can be detected form simulation results. The offshore current (outflow) in front of Rosetta mouth and El-Maadiya outlet can be observed from figs (4-7). Rosetta anticlockwise eddy and the line of divergence can be detected from figs 4-a and 6-a respectively.

In general, there is a good agreement between the simulated results and the previous observations in Abu-Qir Bay.

CONCLUSION

Due to the land runoff of fresh water from Rosetta mouth and brackish water from Lake Edku, Abu-Qir Bay water shows a wide range of salinity variation. Such variation in salinity values causes a significant variation in water density. Therefore density currents take a considerable contribution of water circulation in the Bay.

Princeton Ocean model (POM) was used to simulate the density currents (thermohaline circulation) in Abu-Qir Bay during the different seasons with a horizontal resolution of about 0.5 minute.

The simulation results showed that the density (thermohaline) circulation in the Bay is very complicated. A lot of rotating motions (eddies) can be detected during different seasons. The main features of the surface circulation during **winter** are the extensive anticlockwise eddy in front of Rosetta mouth due to the huge amount of fresh water discharged during this season.

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The water near the bottom has a tendency to flow in reverse manner to that occurred at the surface.

In general, the current speed at surface ranging between 5 to 15 cm/sec while, the near bottom circulation is rarely exceeds 8 cm/sec.

The comparison between the simulation results and the previous measurements shows a good agreement between the simulated circulation patterns and the observed one.

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