Simulation of Wind driven currents for continental shelf of Golestan Province (Iran)

Saeed Sharbaty*
Faculty Member Dept. of fishery, Grogan University of Agricultural sciences & Natural Resource

Abstract
In this Investigation, three dimensional modeling of wind driven currents was done in the continental shelf of Golestan Province using MIKE 3 Model. In order to applying open boundary conditions in both western and northern borders, the results of implemented of two dimensional MIKE 21 model were used in the Caspian Sea. In implementation of MIKE 21 model, reanalysis data of NOAA satellite includes components of wind speed and pressure at sea level with 6 hours time intervals and variable in space and time, as well as input of major rivers and evaporation and Coriolis force is used. In the MIKE 3 HS model, the effects of Atrak, Gorganrood rivers and water exchange with the Gorgan Bay as source and sink has been considered. To applying wind effect on the continental shelf of Golestan Province, the data of Bandartorkaman synoptic station to become changed into the offshore wind. In order to verification of the results of the MIKE 3 model, the flow field measurements were used in two points of solution domain. The model results represented the high influence of wind action on the surface layers and in most cases; currents are along the dominant wind and in direction of southeast area. By moving towards deep area, currents go out from the solution area with the 180 degrees of phase difference from surface currents.

Key Words: Continental Shelf, Golestan Province, 3D Simulation, Wind Driven Currents.

1. Introduction

Sea currents due to their role in nutrients supplying are effective factors on biological primary productions in the water bodies. Therefore, the increasing of primary productions will cause to increasing secondary productions, catching and use of biological resources in the sea. On the other hands, sea currents are the main factors in the distribution of environmental pollutions and with sediments transporting caused to deformation coastal morphology. Knowledge of flow pattern is so necessary for marine structures and engineering projects. Today, utilizing of numerical models is obvious due to dramatic reductions in costs and time in order to simulating of marine phenomena such as current, sedimentation, wave, water level fluctuations and distribution of environmental pollutions. In recent years, MIKE 3 and MIKE 21 models have a special place among countries that is adjacent to the sea. In this investigation, three dimensional modeling of wind-driven flow pattern has been study in sea water of Golestan province (continental shelf zone). As an ecological case, this part of the Caspian Sea due to the low depth and appropriate water temperature is a suitable site for marine aquatic specially the Sturgeons, so that more than 46% of the share extracting of Iranian Sturgeons resources provided from this basin. However, some important ecosystems such as Gomishan wetland, Gorgan Bay and the Miankaleh peninsula, due to their neighboring with it received more effects of marine activities from this basin. Developing of pen cultures of fishes and shrimps in Golestan coats along side of industrial towns nearby this basin and civil projects to construction of Torkaman, Gaz and khajenafas ports and urban pollution brought via two major rivers (Gorgan Rude and Atrak) polluted this basin. There are many studies about hydrodynamic flow in the Caspian Sea and its surround, such as: Sharbaty [23, 24] Zounemat-Kermaniand; et al [29], Ibrayev; et al [6], Ghaffari; et al [5], Esmaeili; et al [4], Knysh; et al [8], Biabani [2], Nasimi; et al [19], Korotenko; et al [9], Panin; et al [20], Bannazadeh; et al [1], Sabbagh-Yazdi [22], Matthew; et al [18], Bondarenko [3], Kosarev [10], Klevtsova [7] and Lednev [11]. The continental shelf of Golestan with less than 0.5 degree gradient has maximum depth of 34 meter and mean depth of 8 meter. This basin with 90 kilometer length and 60 kilometer width, completely located on continental shelf zone. This basin bounded to Mazandaran province waters from west, Golestan province coasts from south and east-southern and Republic of Turkmenistan from northeastern part. The extent of this area is more than 5400 km^2 and its bottom sedimentation has marine and continent resource. The coastal zone of Golestan is so flat and smooth. The aim of this investigation is reaching to wind-driven flow pattern and velocity components (u, v, w) in three dimensional mode in different layers using MIKE 3 in continental shelf of Golestan province.

2. Material and Methods

This work is based on librarian studies, field measurement data performed by Ministry of Jihad-e-Agriculture, meteorology data in Bandartorkaman station, numerical-meteorological data of NOAA site and Implementation of MIKE 21 and MIKE 3 model.

2.1. Model Description, Main Equations and Numerical Formulation in MIKE 21 model

Due to lack of field measuring data of current and surface water elevation in two open boundaries in the solution domain in during 2001/07/20 to 2001/08/20, at first MIKE 21 model was implemented for the Caspian Sea. The hydrodynamic model in the MIKE 21 Flow Model is a general numerical modeling system for the simulation of water levels and flows in estuaries, bay and coastal areas. It simulates unsteady two-dimensional flows in one layer (vertically homogeneous) fluids and has been applied in a large number of studies. The effects of bottom friction stress, wind stress, water elevation for the open boundary condition, eddy viscosity, flood and dry, rivers inflow, precipitation and evaporation considered in MIKE 21 model [12, 13]. The governing equations are written as follows:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \qquad (1)$$

Momentum equation in x-direction:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{c^2h^2}$$

$$-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega_q-fvv_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a)=0 \qquad (2)$$

Momentum equation in y-direction:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{c^2h^2}$$

$$-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+\Omega_p-fvv_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a)=0 \qquad (3)$$

The following symbols are used in the equations:

$h(x,y,t)$ Water depth $(\zeta-d,m)$

$d(x,y,t)$ Time varying water depth (m)

$\zeta(x,y,t)$ Surface elevation (m)

$p,q(x,y,t)$ Flux densities in x-and y- directions ($m^3/s/m$) = (uh, vh); (u,v) = depth Average velocities in x- and y-directions.

$C(x,y)$ Chezy resistance ($m^{1/2}/s$)

g Acceleration due to gravity (9.81 ms^{-2})

$f(V)$ Wind friction factor

$V,V_x,V_y(x,y,t)$ Wind speed and components in x- and y-directions (m/s)

$\Omega(x,y)$ Coriolis parameter, latitude dependent (s^{-1})

$p_a(x,y,t)$ Atmospheric pressure (pa)

ρ_w Density of water (kg/m^3)

x,y,z Space coordinates (m)

t time

$\tau_{xx},\tau_{xy},\tau_{yy}$ Components of effective shear stress

MIKE 21 HD makes use of a so-called Alternating Direction Implicit (A.D.I) technique to integrate the equations for mass and momentum conservation in the space-time domain. The equation matrices that result for each direction and each individual grid line are resolved by a Double Sweep (DS) algorithm [14].

2.2. MIKE 21 Model Setup

For making the bathymetry map of the Caspian Sea, the sheet map of the Caspian Sea with scale of 1:1500000 in WGS 1984 was used. The bathymetry included 63×117 rectangular grids with grid size 10 km in the both zonal and meridional directions in Cartesian coordinate system. Since in the bottom topography modeling, the maximum depth in the Golestan continental shelf is less than 34 meter, in this work, all depths greater than 34 meter was considered equivalent to depths of 34 meters. Wind stress is an important factor to forming surface currents in the Caspian Sea. In this work, the wind data including wind speed (m/s) and wind direction (degree) components in 10 meter high from the sea surface and also surface pressure (hpa) was used as varying in space and time available from a re-analysis data of NOAA site (National Oceanic and Atmospheric Administration) [30]. The time step data was 6 hours (4-times daily) and the resolution was 2.5 degree latitude × 2.5 degree longitude, 63×117 rectangular local grid with grid size 10 km in the both zonal and meridional directions was considered. The wind friction in the sea surface is varying with wind speed, so in order to affect the wind friction factor with wind speed of variations we used smith and banks formula [28]:

$$f(v)=\left\{\begin{array}{lll} f_0 & for & v<v_0 \\ f_0+\dfrac{v-v_0}{v_1-v_0}(f_1-f_0) & for & v_0\le v\le v_1 \\ f_1 & for & v>v_1 \end{array}\right\} \quad (4)$$

$$f_0=0.00013 \quad , \quad v_0=0 \quad m/s$$

$$f_1=0.0026 \quad , \quad v_1=30 \quad m/s$$

Where

v_1, v, v_0 : Are wind speed

f_0, f_1 : Wind friction parameter

Discharge of five main rivers to the Caspian Sea (Volga, Ural, Terek, Kura and Sefidrud) as source terms, water outflow to the Kara-Bogaz-Gol and evaporation as sink terms, the Coriolis forcing included in the model. Considering factors in MIKE 21 model briefly explain in table 1.

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Table 1- considering factors in MIKE 21 model

Module Selection	Hydrostatic	Simulation Start Date	2001/07/20
Map Projection	Lat & long	Simulation End Date	2001/08/20
Time Step Range	4464	Max Courant Number	1.09
Time Step Interval (s)	600	Number of sources	5
Flooding & Drying Depth (m)	0.2 , 0.3	Number of sink	1
Initial Surface Elevation (m)	0	Evaporation (mm.day^{-1})	6
Precipitation (mm.day^{-1})	0	Eddy Viscosity (Smagorinsky Velocity Based) (m^2.s^{-1})	0.5
Resistance(Manning Number) (m$^{1/3}$.s^{-1})	32	Wind Conditions (m.s^{-1})	Varying in time and space

To verify the results of MIKE 21 model, flow pattern obtaining from MIKE 21 model compared to document reports in the reasonable resources (figs 2, 3). At the next step, mean velocity components $\bar{u}, \bar{v}$ and water level extracted as two profile series in west and north boundary (fig 1).

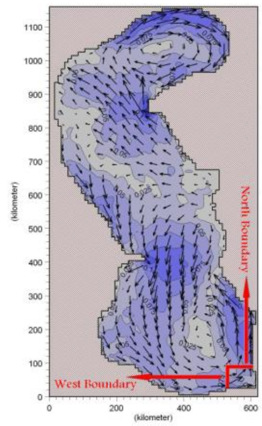

Figure 1- 2D flow pattern in the Caspian Sea by MIKE 21 model and location of west and north boundaries.

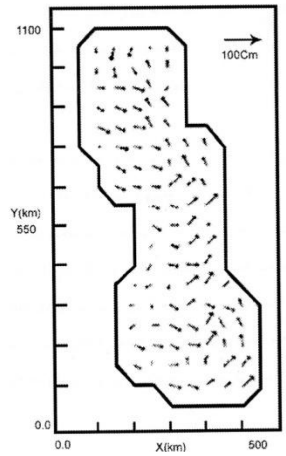

Figure 2- main surface flow pattern of the Caspian Sea in the stationary mode by numerical model done by Bannazadeh (2002).

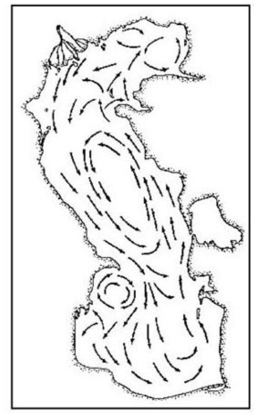

Figure 3- Scheme of the Caspian Sea currents by Ledinov (1943).

2.3. Model Description, Main Equations and Numerical Formulation in MIKE 3 Model

In this study, the MIKE 3 HD model was used for three dimensional simulation of flow pattern in the Golestan continental shelf. The hydrostatic (HS) model in MIKE 3 HD is a general numerical modeling system for simulation of unsteady three-dimensional flow in estuaries, bays and coastal areas as well as in lakes and oceans. It simulates flows taking into account bathymetry and external forcing such as meteorology, tidal elevations, currents and other hydrographic conditions [15, 16]. The mathematical foundation for the standard MIKE 3 HD engine is the mass equation and the Reynolds-averaged Navier-Stokes equation, including an artificial compressibility (ACM) due to the chosen numerical solution procedure. The hydrodynamic module of MIKE 3 makes use of the so-called Alternating Direction Implicit technique to integrate the equations for mass and momentum conservation in the space-time domain. The equation matrices, which result for each direction and each individual grid line, are solved by Double Sweep algorithm. These equations read [17] (only X-direction is shown for 2nd equation):

$$\frac{1}{\rho c_s^2}\frac{\partial P}{\partial t}+\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=S_{MASS} \qquad (5)$$

$$\frac{\partial u}{\partial t}+\frac{\partial uu}{\partial x}+\frac{\partial uv}{\partial y}+\frac{\partial uw}{\partial z}+2\omega\big(-v\sin(\phi)+w\sin(\phi)\sin(\lambda)\big)=$$

$$-\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}(2\upsilon_t\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}\left(\upsilon_t(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x})\right)$$

$$+\frac{\partial}{\partial z}\left(\upsilon_t(\frac{\partial u}{\partial z}+\frac{\partial v}{\partial z})\right)+u_{ss}S_{MASS} \qquad (6)$$

Where

ρ Density

c_s Speed of sound in water

u, v, w Velocities in x,y,z directions

ω Coriolis parameter

ϕ, λ Latitude, Longitude

υ_t Turbulent eddy viscosity

S_{MASS} Source/sink term with

$$S_{MASS} = \sum_{i_s=1}^{N_s} \delta(x - x_{s,i_s}, y - y_{s,i_s}, z - z_{s,i_s}) Q_{s,i_s}$$

δ Delta function of source/sink coordinates m^{-3}

$x_{s,i_s}, y_{s,i_s}, z_{s,i_s}$ Coordinates of source/sink NO. i_s

Q_{s,i_s} Discharge at source/sink NO. i_s, m^3/s

The differences between MIKE 3 HS and MIKE 3 ACM are:

A hydrostatic pressure assumption is applied, i.e. the vertical accelerations are assumed to be negligible. The vertical velocity w is assumed negligible, resulting in the removal of the secondary Coriolis term and the last diffusion term. The pressure is split up into two parts, the external pressure and the internal pressure. The external pressure is directly linked to the free surface, and the internal pressure is due to the density differences. The fluid is assumed incompressible, as opposed to the standard version of MIKE 3 HD. Consequently, the compressibility term in the mass equations is discarded.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = S_{MASS} \qquad (7)$$

$$\frac{\partial u}{\partial t} + \frac{\partial uu}{\partial x} + \frac{\partial uv}{\partial y} + \frac{\partial uw}{\partial z} - 2\omega v \sin(\phi) = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}(2\upsilon_t \frac{\partial u}{\partial x})$$
$$+ \frac{\partial}{\partial y}\left(\upsilon_t (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})\right) + \frac{\partial}{\partial z}\left(\upsilon_t (\frac{\partial u}{\partial z})\right) + u_{ss} S_{MASS} \qquad (8)$$

The external/internal pressure gradient force is given by:

$$\frac{1}{\rho}\frac{\partial P}{\partial x} = g\frac{\rho(\zeta)}{\rho}\frac{\partial \zeta}{\partial x} + \frac{g}{\rho}\int_z^\zeta \frac{\partial \rho}{\partial x} dz \qquad (9)$$

Where

g Acceleration due to gravity

ζ Surface elevation

In the ACM version of MIKE 3, the top horizontal layer containing the free surface is solved separately from, but not independently of, the underlying cells. The top layer is layer-integrated as opposed to the underlying cells. In the hydrostatic version of MIKE 3, the equations to be solved are in their layer-integrated form for both the top layer and the underlying cells. This is due to the solution procedure, where it is convenient to have the same formulation for all cells in each water column. Assuming that the horizontal velocities are constant over the layer thickness. The layer-integrated form of (7)-(8), with the pressure gradient force inserted, is:

$$\frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} + w_{top} - w_{bot} =$$
$$P - E + \sum_{i_s} \delta(x - x_{s,i_s}, y - y_{s,i_s}) Q_{s,i_s} \qquad (10)$$

$$\frac{\partial uh}{\partial t} + \frac{\partial uuh}{\partial x} + \frac{\partial uvh}{\partial y} + (uw)_{top} - (uw)_{bot} - 2\omega v h \sin(\phi) =$$
$$-gh\frac{\partial \zeta}{\partial x} - \frac{g}{\rho}\int_{layer}\left(\int_{z'}^{\zeta}\frac{\partial \rho}{\partial x}dz'\right)dz + \frac{\partial}{\partial x}\left(2\upsilon_t h\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}(\upsilon_t h\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right))$$
$$+\upsilon_t(\frac{\partial u}{\partial z})_{top} - \upsilon_t((\frac{\partial u}{\partial z})_{bot} + u_{ss}\sum_{i_s}\delta(x - x_{s,i_s}, y - y_{s,i_s})Q_{s,i_s} \qquad (11)$$

Where the sums represent all point source/sink in the considered layer, and precipitation and evaporation terms, P and E (m/s), have been expluded from the sum. The precipitation and evaporation terms is only included if the considered layer is the surface layer. The depth-integrated version of (10) is:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial UH}{\partial X}+\frac{\partial VH}{\partial Y}=P-E$$
$$+\sum_{i_s}\delta(X-X_{s.i_s},Y-Y_{s.i_s})Q_{s.i_s} \qquad (12)$$

With sum over all point source/sinks. The turbulence is modeled in terms of an Eddy Viscosity and a bed shear stress. In this study, we used mixed 1D $-\varepsilon$, 2D Smagorinsky Turbulence model for determined horizontal and vertical eddy viscosity. The horizontal eddy viscosity is determined by Smagorinsky formula [27].

$$\upsilon_T = L^2\sqrt{S_{ij}.S_{ji}} \qquad (13)$$

$$S_{ij}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right) \qquad (14)$$

u_i Are the velocity components in the $x_i -$directions. L Is a length scale and for the vertical direction, a 1D $k-\varepsilon$ model is applied.

$$\upsilon_T = C_\mu \frac{k^2}{\varepsilon} \qquad (15)$$

k The turbulent kinetic energy

ε The dissipation rate of turbulent kinetic energy

C_μ Is an empirical constant

The bed stress is specified in terms of a drag coefficient formulation according to the relation,

$$\frac{\tau_{bottom}}{\rho}=C_D u^*\left|u^*\right| \qquad (12)$$

τ_{bottom} Is the bottom shear stress

u^* The first computational speed encountered above the bottom.

C_D Is the drag coefficient.

When using the mixed 1D $-\varepsilon$, 2D Smagorinsky closure model, the bed drag coefficient reads

$$\frac{\tau_{bottom}}{\rho}=C_D u^*\left|u^*\right| \qquad (16)$$

Z_b Is the vertical extent of the bottom grid cell

K Is von karmans constant

c_s Is bed roughness length scale

2.4. MIKE 3 Model Setup

In this study, due to lack of access to temperature and salinity field data in period of the modeling, the effects of these factors were negligible. To make the bathymetry model of Golestan continental shelf, the sheet map with scale of 1:100000 were used. Model area has to be rectangular in horizontal plane. A Cartesian coordinate system was selected and the model domain was divided into 60 × 90 square grids with a grid size of 1000 m. In order to calibration of the model and according to the depths of field measurements of flow velocity, the vertical grid spacing is chosen as 0.5 meter. After running the model for several times and changing some important calibration coefficients such as bottom friction and wind friction factor in surface, model was calibrated. For verification of the model, the current measurement data were used by Ministry of Jihad-e-Agriculture in southern part of the domain [21]. For evaluating the model results the Root mean square error formula was used to compare the percentage of errors (table 2).

Table 2- Comparing the results of modeling and field measurements, percent errors in the two situations.

Date	Station	lat (degree)	Long (degree)	Total depth (m)	Measurment depth (m)	Current Meter (m.s^{-1})	Model (m.s^{-1})	percent error
2001/08/01	B_1	36 55 00	54 02 18	1/9	0.4	0.1	0.09	0.1
					1.2	0.22	0.24	0.09
					1.6	0.24	0.19	0.2
	B_3	36 55 00	54 01 23	2/3	0.4	0.21	0.18	0.14
					1.4	0.2	0.21	0.05
					1.8	0.23	0.25	0.08

At the next stage and after the model calibration, according to the maximum depth of the basin (-34 meter), the vertical grid spacing chosen as 2 meter. Thus the model includes 17 separately vertical layers. In the present study, the results output of MIKE 21 for the Caspian Sea as a profile series including velocity components and water surface elevation in west and north boundaries as boundary conditions in two open boundaries of the basin in western and northern parts of it were used. In the period of the study, wind data including speed and direction as varying with time but constant in space for the Gorgan Bay were gathered from Bandartorkaman synoptic station after transform to offshore wind [26]. To implement the initial surface condition, the results of two dimensional modeling of the Caspian Sea was used. Mean discharge of Gorgan Rud and Atrak river included in the model as source terms. The Gorgan Bay located at the southeast part of the Golestan coastlines has an important role in forming the flow pattern in southeast part of the solution domain, so in this study the effects of water exchange between the Gorgan Bay and this basin was considered to modeling [25]. Table 3 shows the including factors in MIKE 3 model after calibration the model.

Table 2- considering factors in MIKE 3 model

Module Selection	Hydrostatic	Simulation Start Date	2001/07/20
Map Projection	WGS-1984-UTM-Zone-38N	Simulation End Date	2001/08/20
Time Step Range	4464	Max Courant Number	10/53
Time Step Interval (s)	600	Number of sources	2
Flooding & Drying Depth (m)	0.2 , 0.3	Number of sink	1
Initial Surface Elevation (m)	From file Dfs2 of MIKE 21	Evaporation (mm.day^{-1})	6
Precipitation (mm.day^{-1})	0	Turbulence model	$k-\varepsilon$ Mixed/Smagorinsky formula
Resistance (Manning Number) (m$^{1/3}$.s^{-1})	30	Wind Conditions (m.s^{-1})	Varying in time and space
Number of Vertical Layers	17	Apply Coriolis forcing	yes
Vertical grid spacing (m)	2	Boundary condition	data transfer (Velocity-dfs1)
Background salinity (psu)	13	Background temperature (^{0}c)	27
Warm-Up (day)	3	Number of computational points	437462

3. Discussion

It is necessary in MIKE 3 model to have useful boundary data to three dimensional simulating the wind-driven flow pattern. This basin has two open boundaries in western and northern parts. For extracting of water elevation and velocity components in the plan on the open boundaries, the results of MIKE 21 model were used in the Caspian Sea. MIKE 3 model was run after implemented the boundary conditions and transformed the coastal wind to offshore wind. The model results were verified in two points of the domain. Notice that the time step intervals in this simulation was 600 second and model was run for one month (2001/07/20 to 2001/08/20). In this section, mean monthly of MIKE 3 modeling results will be described.

3.1. Currents description in the coastal zone

Generally costal currents are along the coast and reciprocating in period of the simulation. In south part of the domain and above the Miankaleh peninsula currents almost are parallel to the peninsula and flow from west to east (fig 4). Model calculated maximum speed value about 0.45 m/s along these coasts. In west part of the coasts with moving from south to north, the speed values will be increased, such that maximum current speed in north coast is taking to 0.3 m/s. Flow pattern in the west coasts are depending to prevailing wind pattern and currents flow to the south along the north-south axis. Current speed with increasing the depth is decreased in shallow water in coastal zone because of the bottom friction and friction between adjacent layers. Golestan continental shelf divided in to northern and southern parts in order to estimating currents in the surface layer at the offshore areas. In surface layer of the northern part, currents mostly flow to southeast along the prevailing northwest wind. But in surface layer of the south part of the domain, currents affected by bottom topography and shifting their direction to the southeast in most of the time with maximum speed of 0.45 m/s.

3.2. Currents description in middle layer

Currents review in the middle layer in depth of 17 meter shows that this layer has much effectively from surface layer. Wind stress has a main role in forming of the current circulation in this layer. In northern part of this basin, currents deviated to the north and northwest. Maximum current speed in this layer was recorded in deeper parts of the continental shelf and is about 0.3 m/s. This high current speed was occurred because of the effect of high current speed in west open boundary that is effecting by fast and anticlockwise currents in the Caspian Sea. This layer at the southern part, getting a little effect from wind pattern in the surface layer and the current speed in this part is so low because this part is a shallow water zone and affected by bottom topography. Maximum current speed in this layer is about 0.1 m/s. Mean monthly of modeling results show that there is an anticlockwise ring in south part of this basin and in north part of it clockwise ring can be seen (fig 5).

3.3. Currents description in deep layer

In generally, current directions in depth of 28 meter are to the northwest. Such that current directions in these depths have about 180 degree phase difference with surface currents that mostly flow to the southeast. This occurrence indicated on outflow water in this depth from this basin. Maximum current speed in this part by affecting the bottom friction is about 0.14 m/s in this layer (fig 6).

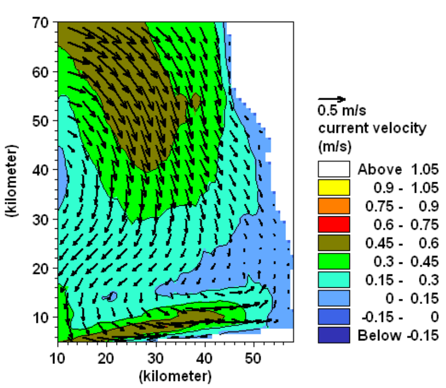

Figure 4- mean monthly flow pattern and velocity distributions in the surface layer.

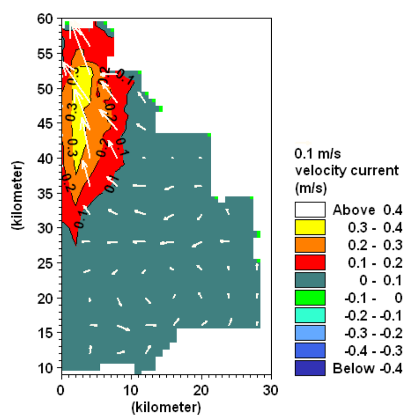

Figure 5- mean monthly flow pattern and velocity distributions in the middle layer (17 meter depth).

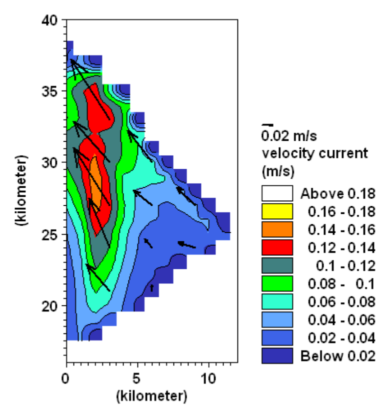

Figure 6- mean monthly flow pattern and velocity distributions in 28 meter depth.

4. Conclusion

The results in this study are a mean monthly from 2001/07/20 to 2001/08/20. To obtain better results, model must be implemented for at least one year period with including the effect of salinity and temperature variations. In this investigation because of lack of temperature and salinity field data in period of the modeling, the effect of these factors were negligible. Generally the modeling results are as follow:

1- In costal lines of Golestan continental shelf, currents are along the coast and reciprocating. This result is completely matched to two dimensional modeling by MIKE 21 model that was done by Rahimpoor Anaraky (2005) [22]. Due to effective bed friction in coastal lines, surface current speed in these areas is lower than offshore surface currents.

2- Modeling results of the middle layer show that there is an anticlockwise ring in southern part of this layer and in northern part of it clockwise ring can be seen. The effects of north and west open boundaries and prevailing wind pattern have an important role to forming these rings.
3- Current direction in deep part of the basin is to the northwest has about 180 degree phase difference with surface currents. This occurrence indicated on outflow water in this depth from this basin.

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