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Three Dimensional Modeling of Caspian Sea Currents Using FVCOM MODEL

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1 INTRODUCTION

Caspian Sea is the biggest lake in the world containing 43% of the global volume of lacustrine waters. Compared to other lakes in the world, Caspian Sea is still unknown in many ways. There are a lot of oil extraction projects taking place in different regions of the Caspian Sea. On the other hand several unique and endangered pelagians live in this Sea which may be damaged if any oil pollution diffused in the Caspian Sea.

Water circulation has the main impact on oil pollution diffusion in the Seas, therefore it is essential to understand the general and local circulations in the Caspian Sea to have a suitable rescue plan ready in case of oil spill hazard. There has been a lack of current data in the Caspian Sea in spite of the history of observations in the Caspian Sea for more than 50 years (Knysh et al., 2008), therefore researchers started to use numerical models to simulate water circulation in Caspian Sea among them Knysh et al. (2008), Popov et al. (2009), Ibrayev et al. (2010), Kara et al. (2010), Zounemat-Kermani and Sabbagh-Yazdi (2010), Sharbaty (2012) and Turuncoglu et al. (2013).

In this paper we have used FVCOM model to simulate and study the water circulation in the Caspian Sea as the first step of oil spill study in the Caspian Sea. Water circulation has been modeled as a result of wind stress and river inflow. The simulation is conducted based on 1982 atmospheric data since it has the minimum Sea level change between the first and last day of the year (Ibrayev et al., 2010).

1.1 *Numerical Modeling*

1.1.1 *FVCOM Model*

FVCOM is a three dimensional ocean model including a combination of both finite difference and finite element models, The governing equations consist of the following momentum, continuity, temperature, salinity, and density equations (Chen et al., 2006):

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}+\frac{\partial u}{\partial z}=0 \qquad (1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_o}\frac{\partial P}{\partial x}+\frac{\partial}{\partial z}(K_M\frac{\partial u}{\partial z})+F_x \qquad (2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_o}\frac{\partial P}{\partial y}+\frac{\partial}{\partial z}(K_M\frac{\partial v}{\partial z})+F_y \tag{3}$$

$$\frac{\partial P}{\partial z}=-\rho g \tag{4}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{\partial}{\partial z}(K_h\frac{\partial T}{\partial z})+F_T \tag{5}$$

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=\frac{\partial}{\partial z}(K_h\frac{\partial S}{\partial z})+F_S \tag{6}$$

$$\rho=\rho(T,S) \tag{7}$$

where *x*, *y*, and z are the Cartesian coordinate system; *u*, *v*, and *w* are the *x*, *y*, *z* velocity components; *T* is the temperature; *S* is the salinity; ρ is the density; *P* is the pressure; *f* is the Coriolis parameter; *g* is the gravitational acceleration; K_m is the vertical eddy viscosity coefficient; and K_h is the thermal vertical eddy diffusion coefficient. F_u , F_v , F_T, and F_S represent the horizontal momentum, thermal, and salt diffusion terms. The total water column depth is $D = H + \zeta$ where *H* is the bottom depth (relative to *z* = 0) and *z* is the height of the free surface (Chen et al., 2006).

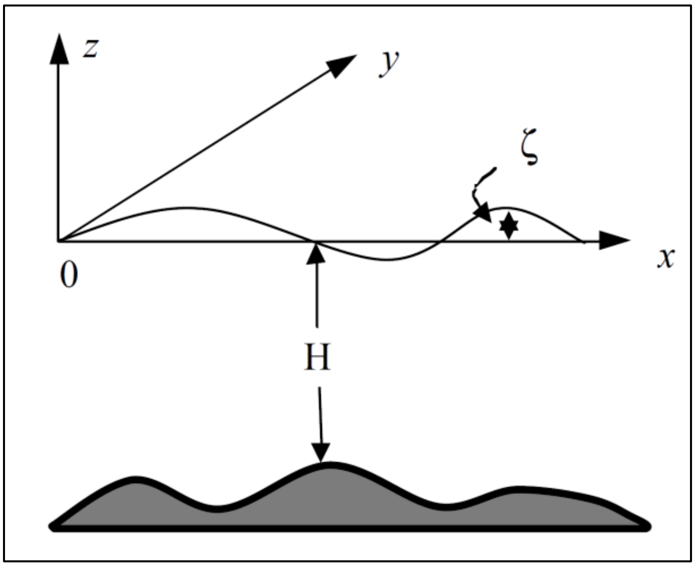

Figure 1. Orthogonal coordinate system in FVCOM, (Chen et al., 2006)

1.1.2 *Model Inputs*

The simulation was conducted based on 1982 atmospheric data since it has the minimum Sea level change between the first and last day of the year (Ibrayev et al., 2010). Model inputs are consisting of bathymetry and coastline boundary, wind velocities, rivers discharge.

The bathymetry and coastline boundary were provided from NOAA (National Oceanic and Atmospheric Administration) website. The bathymetry data grid dimension was 0.5'×0.5', Figure (2) shows the Caspian Sea bathymetry used in this simulation, as one could see, the Kara-Bogaz-Gol depression was omitted in this simulation because it was believed to have no effect in the Caspian Sea general circulation. As it is clear in this figure, the deepest part of the Caspian Sea is located in the South, near Iran.

Wind velocities including of 10m *U* and *V* velocities were prepared from ECMWF in a 0.75'×0.75' grid and in 3 hours periods. River discharges were prepared from GRDC (Global Runoff Data Centre) for Volga, Kura and Ural which respectively have the most discharge into the Caspian Sea, Figure (3) shows the monthly discharge of these three rivers during 1982.

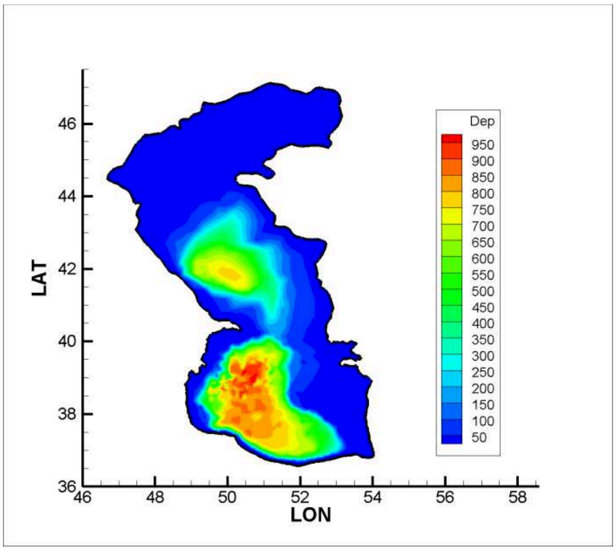

Figure 2. Caspian Sea bathymetry prepared by NOAA

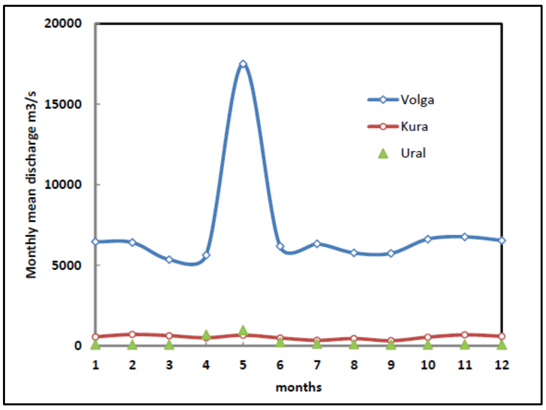

Figure 3. Monthly discharge of Volga, Kura and Ural during 1982 into the Caspian Sea

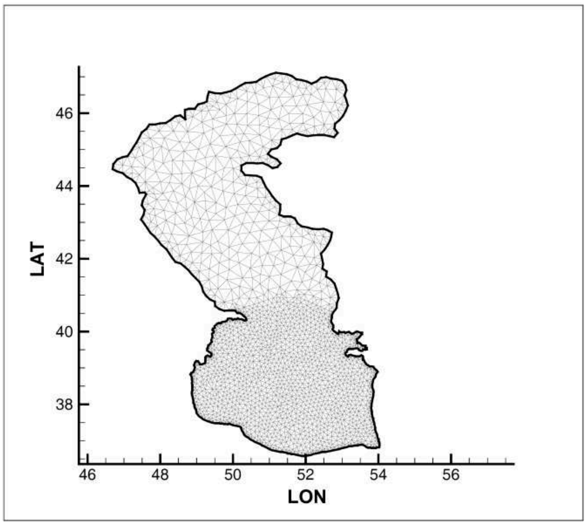

Figure 4. Model unstructured mesh

1.1.3 *Model Setup*

The simulation area was discretized into a triangular mesh with 3864 elements and 2186 nodes as it can be seen in figure (4). Since the South part of the Caspian Sea is more important in this research because it is in vicinity of Iran, the lower part of the domain has been discretized with smaller mesh. Therefore the element edge size was about 3 kilometers long in the lower part and gradually reached to 30 kilometer in the upper part of domain. The simulation domain was discretized to 15 layers vertically. The simulation start with a cold start, to reach the quasi-stationary periodical states the model was run for two years and the first year results were eliminated.

1.2 *Results and Discussions*

The results of current speeds in the second year have been monthly averaged and illustrated in Figure (5). As it could be seen in this Figure, in most months, three or four general circulation could be recognized for each month. The circulation patterns were compared with Ibrayev et al. (2010), Figure (6) which shows acceptable agreement between them.

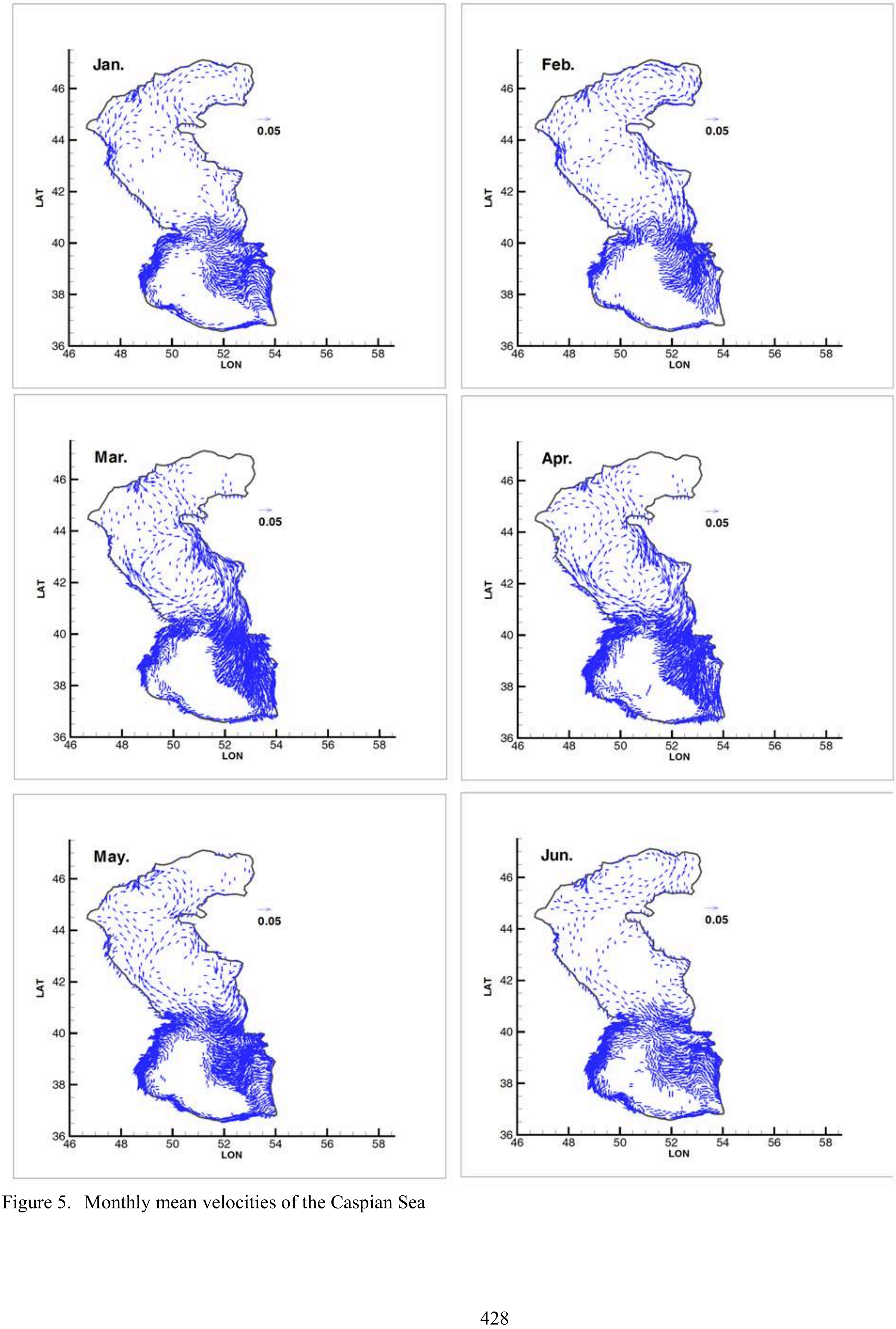

Figure 5. Monthly mean velocities of the Caspian Sea

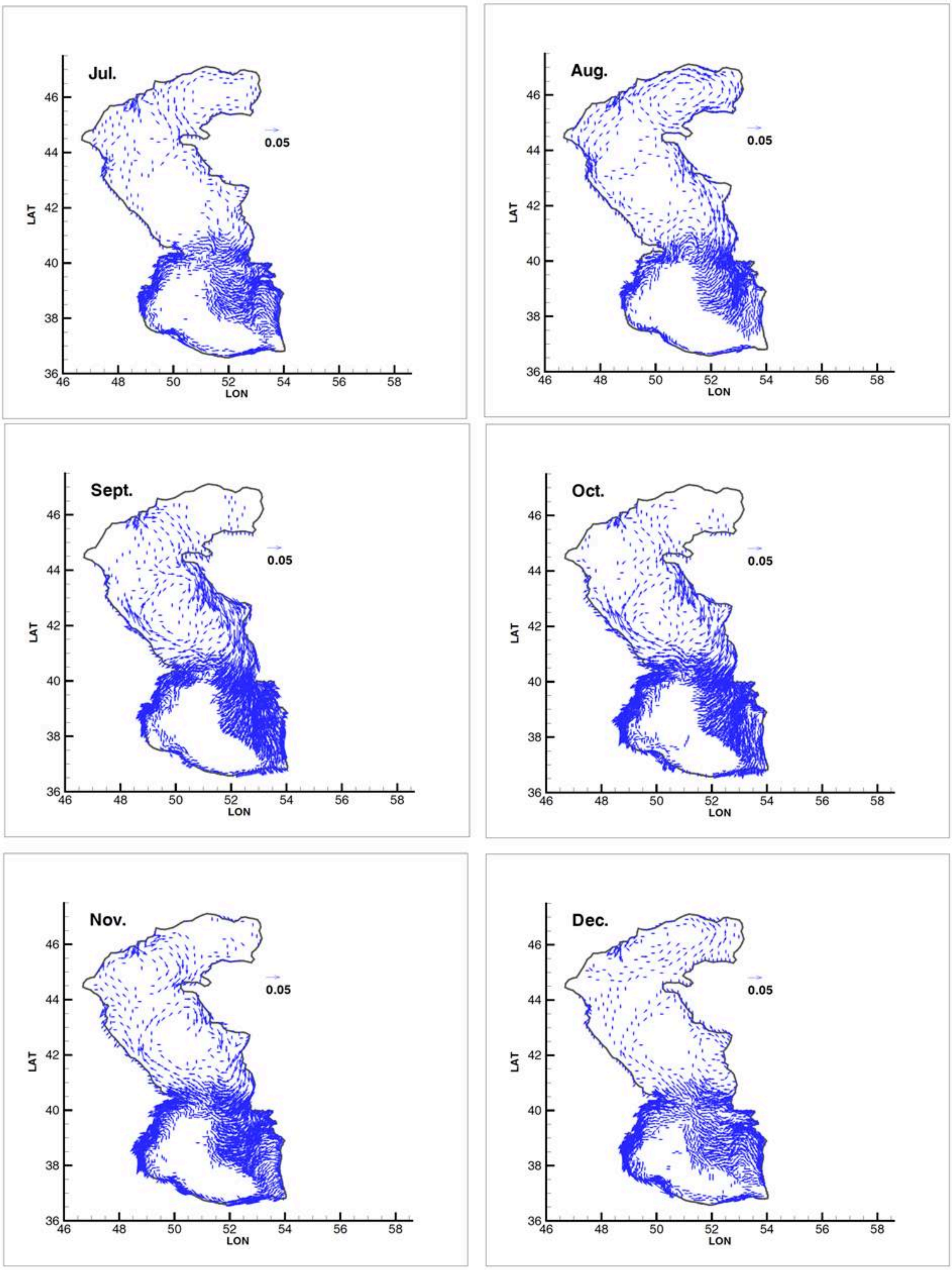

Figure 5. Continued

As it could be seen in all figures, the computed current velocities are negligible in the deepest part of the domain, this miscalculating could be due the increasing of vertical mesh in this parts, increasing the vertical layers may solve this problem.

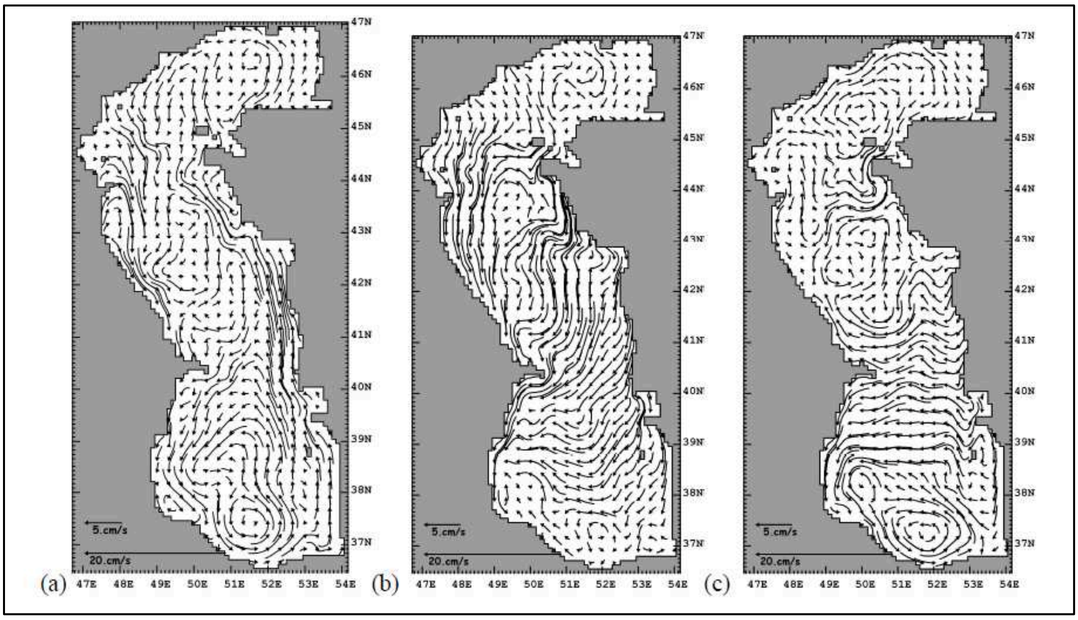

Figure 6. Monthly mean sea surface currents (cm/s) for the months of **(a)** December, **(b)** May and **(c)** August, (Ibrayev et al., 2010)

NOTATION

x, y, and z	Cartesian coordinate system
u, v, and w	x, y, z velocity components
S	salinity
T	temperature
ρ	density
P	pressure
f	Coriolis parameter
g	gravitational acceleration
K_m	vertical eddy viscosity coefficient
K_h	thermal vertical eddy diffusion coefficient
F_u	horizontal momentum
F_v	vertical momentum
F_T	thermal diffusion term
F_S	salt diffusion terms

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