Conference Paper, Published Version

Hajivalie, Fatemeh; Khoshkholgh, Ali Jafar; Mazaheri, Said

Three Dimensional Modeling of Caspian Sea Currents Using FVCOM MODEL

ICHE 2014, Hamburg - Lehfeldt & Kopmann (eds) - © 2014 Bundesanstalt für Wasserbau ISBN 978-3-939230-32-8

Three Dimensional Modeling of Caspian Sea Currents Using FVCOM MODEL

F. Hajivalie, A. Jafar Khoshkholgh & S. Mazaheri
Iranian National Institute for Oceanography and Atmospheric Sciences, Tehran, Iran

Keywords: Water circulation, Wind stress, Heat flux, Lacustrine water

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):

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}+\frac{\partial u}{\partial z}=0 \tag{1}$$

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

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

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

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

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

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

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).

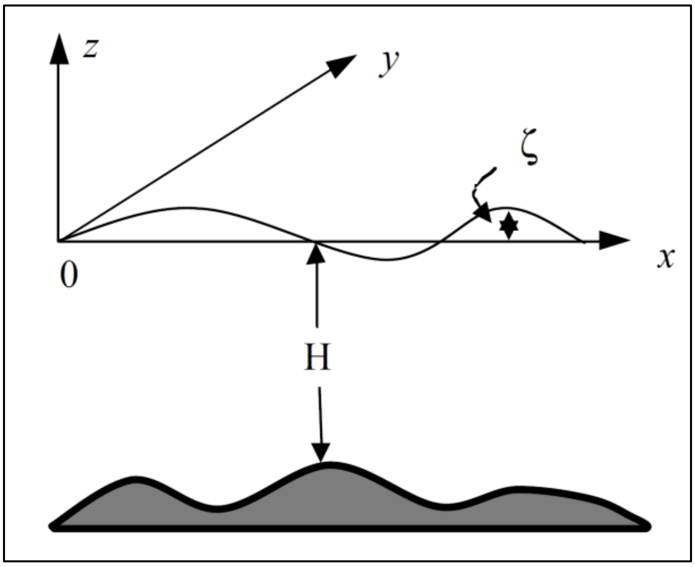

Figure 1. Orthogonal coordinate system in FVCOM, (Chen et al., 2006)

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.

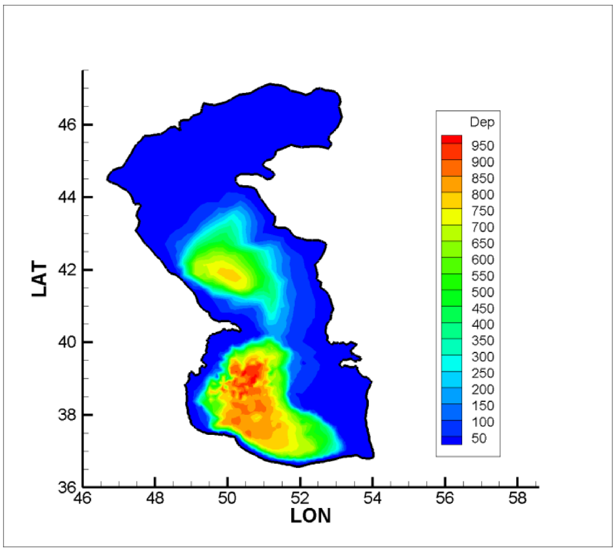

Figure 2. Caspian Sea bathymetry prepared by NOAA

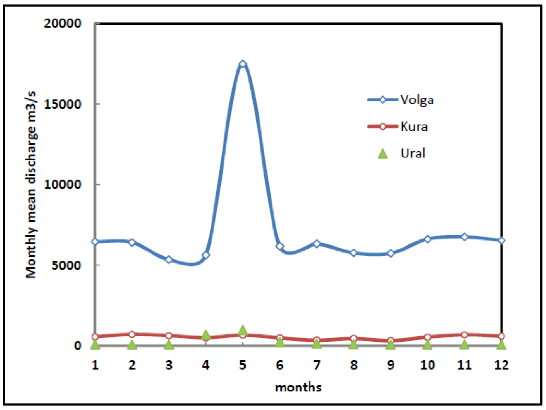

Figure 3. Monthly discharge of Volga, Kura and Ural during 1982 into the Caspian Sea

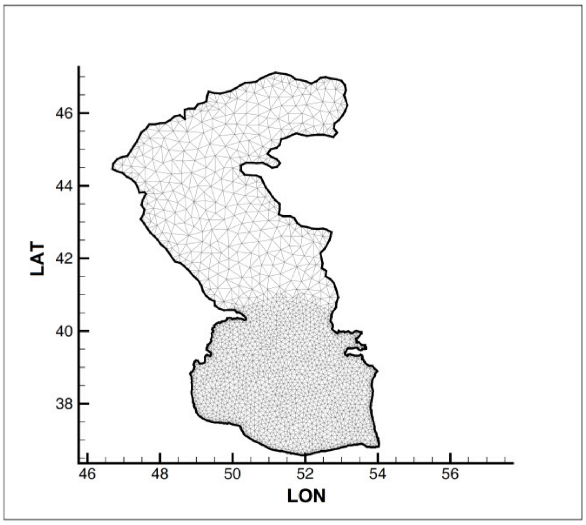

Figure 4. Model unstructured mesh

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.

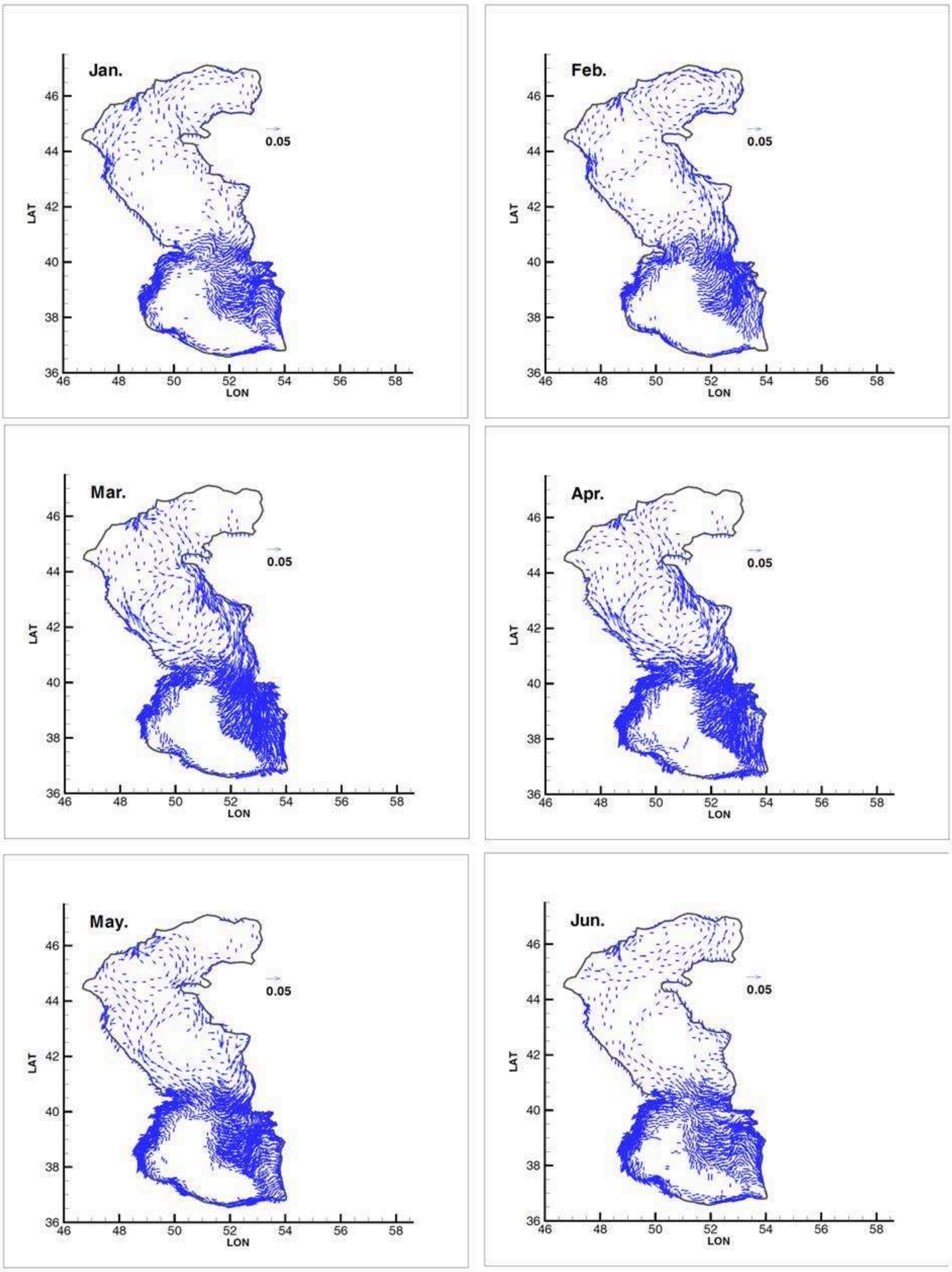

Figure 5. Monthly mean velocities of the Caspian Sea

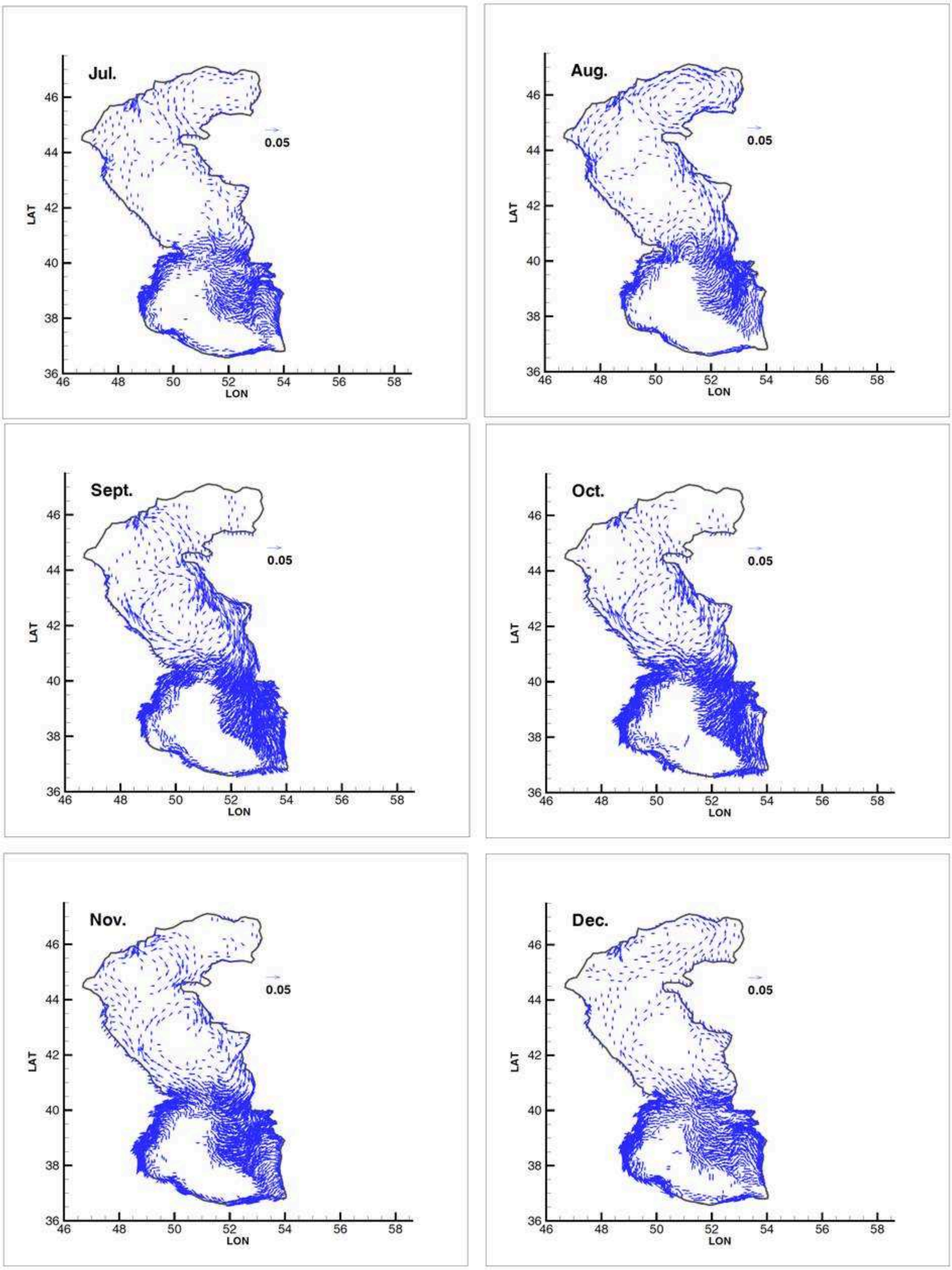

Figure 5. Continued

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.

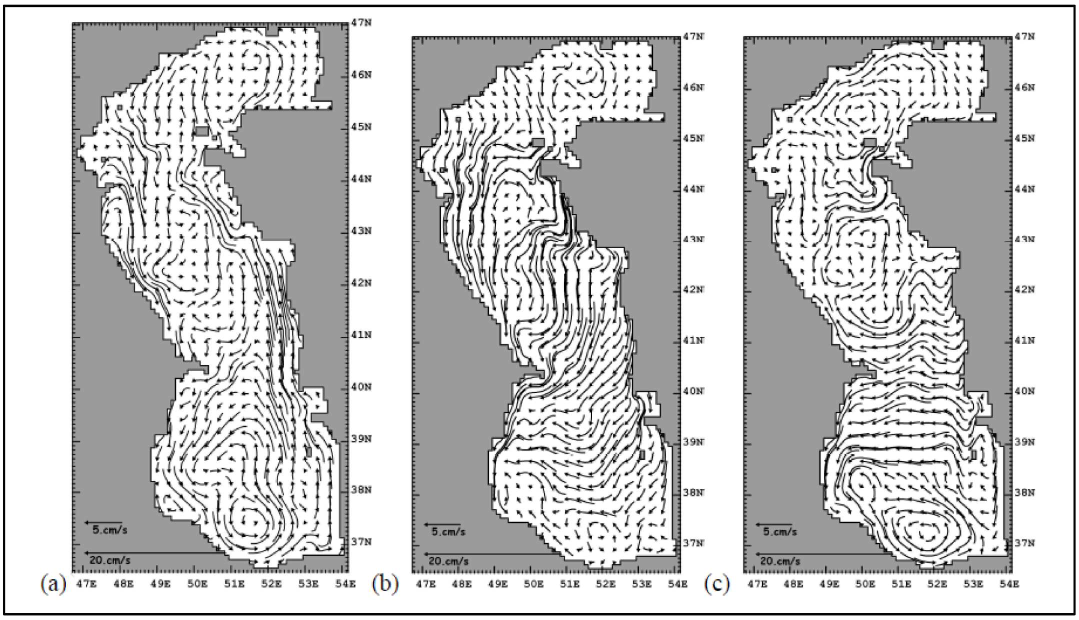

Figure 6. Monthly mean sea surface currents (cm/s) for the months of **(a)** December, **(b)** May and **(c)** August, (Ibrayev et al., 2010)

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

REFERENCES

Chen, C. S., Beardsley, R. C., and Cowles, G., (2006): An unstructured grid, finite-volume coastal ocean model–FVCOM user manual, School for Marine Science and Technology, University of Massachusetts Dart-mouth, New Bedford, Second Edition. Technical Report SMAST/UMASSD-06-0602, 318pp.

Ibrayev, R. A., Özsoy, E., Schrum, C., and Sur, H. I., (2010): Seasonal variability of the Caspian Sea three-dimensional circulation, sea level and air-sea interaction, Ocean Sci., 6, 311–329.

Kara A. B., Wallcraft A. J., Metzger E. J., Gunduz M., (2010) Impacts of freshwater on the seasonal variations of surface salinity and circulation in the Caspian Sea. Cont Shelf Res 30:1211–1225

Knysh, V. V., Ibrayev, R. A., Korotaev, G. K., Inyushina, N. V., (2008): Seasonal variability of climatic currents in the Caspian Sea reconstructed by assimilation of climatic temperature and salinity into the model of water circulation, Atmospheric and Oceanic Physics, 2008, Vol. 44, No. 2, pp. 236–249.

Popov, S. K., Zil'bershtein, O. I., Lobov, A. L., Chumakov, M. M., (2009): Simulation of Seasonal Variations of the Caspian Sea Level Using Parallel Computations, Russian Meteorology and Hydrology, Vol. 34, No. 12, pp. 801–809.

Sharbaty S (2012). 3-D Simulation of Wind-Induced Currents Using MIKE 3 HS Model in the Caspian Sea, Canadian Journal on Computing in Mathematics, Natural Sciences, Engineering and Medicine, Vol. 3, No. 3, pp. 45-54.

Turuncoglu, U. U., Giuliani, G., Elguindi, N., and Giorgi, F., (2013): Modelling the Caspian Sea and its catchment area using a coupled regional atmosphere-ocean model (RegCM4-ROMS): model design and preliminary results, Geosci. Model Dev., 6, 283-299.

Zounemat-Kermani, M. and Sabbagh-Yazdi, S. R., (2010):Conjunction of 2D and 3D Modified Flow Solvers for Simulating Spatiotemporal Wind Induced Hydrodynamics in the Caspian Sea, Journal of Oceanography and Science, Vol.45, no.2, pp:113-128.