Effects of physical parameters on coastal currents due to density difference and tide at Northern regions of Persian Gulf

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Abstract

Sea currents are among the most important issues in dynamical oceanography. In this study, using comprehensive MIKE software, sea currents were modeled by implementing physical sea parameters such as temperature and salinity at Persian Gulf region. Based on this research, the results showed that the speed of current along the longitudinal length of Persian Gulf is very stronger than the speed of the current along the lateral of the Persian Gulf. Despite the fact that there is a significant difference from winter to summer in terms of temperature and salinity but because of the low depth of the Persian Gulf, the temperature and salinity differences are very little at sea bed and surface levels over seasons. The Persian Gulf is approximately homogeneous in terms of temperature, salinity, and tide and no considerable layer differences occur. In winter, the surface temperature of the Oman Sea and Hormuz Strait is low at deep water is and it increases towards the coastal areas and shallow water. In contrast, in summer, the temperature has the highest values in deep waters and it decreases towards the low-depth areas. In winter, in deeper area of the Persian Gulf, the surface salinity has the maximum values, and in the low-depth coastal line and the inlets there are more salinity.

Key words: Persian Gulf; Coastal currents; Density difference; Tidal currents; MIKE 21.

1. Introduction

Sunlight creates sea and atmospheric currents. These currents are able to transfer the received heat from the equator to the poles. However, the atmosphere is one and a half time more influential in heat transference because of its higher speed of movement compared to ocean currents. In addition, several other factors such as tide, rotation, syndrome, types of winds, water pressure, density, and waves lead to sea currents that can be divided into some main groups as follows (Stewart, 2008):

1. Tidal currents
2. Wind driven currents
3. Density difference Currents
4. Geostrophic Currents (caused by the earth rotation or the Coriolis force and intersection slope of two layers)

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At the depth of the sea, the effect of wind and atmospheric factors are very partial and in fact they have no role, and the tide factor only influences the surface layer. At depths the sloping seabed and the difference of density are very significant. Thermohaline currents are created when the variations of temperature and salinity of seawater depend on density changes. Uprising of water level is simply under the influence of thermal source because of mass correlation (Stewart, 2008). The ruling equations on the movement of fluid in terms of temperature, salinity, and density are very significant. In transferring such currents, temperature has more significance. Salinity is also important in terms of dynamics. However, the influence of salinity is less than temperature. In cases such as atmosphere and ocean, the currents are created because of the sunlight heats the environment unequally due to the horizontal difference of temperature. In these fluids, there is a sharp competition between the sunlight, which creates horizontal temporal difference with density, which tries to eliminate this difference. The influence of earth circulation makes these currents more complicated. The currents in which thermal differences are implemented either internally or externally are usually introduced as syndrome. In addition, the thermal transference is very significant as well. In currents where differences of density (salinity), mass transference would be significant, because salinity and temperature are among the sea features and create syndrome called thermohaline. Because of temperature and salinity variations, the density would also change. If the effects of these parameters were considered in a dynamic analysis, the problem would be very complicated. Therefore, Boussinnesq approximation as a simpler method is implemented. In this method, all other physical feature changes except for density and gravitational (Archimedean) forces are excluded. Determining the pattern of sea currents are among the most important issues in oceanography dynamics. Different studies carried out in Persian Gulf region and other ocean waters, open seas, and different gulfs across the world introduced in the following parts:

Torabi Azad *et al.* (2010) studied the qualitative and quantitative changes of Geostrophic currents in Persian Gulf. In the study, using data analysis on the collected data and the density diagrams, it concluded that bi-layer model and bi-layer boundary slope model are the best models to analyze Geostrophic current in Persian Gulf. The speed of Geostrophic currents near the mouth of the Hormuz Strait were calculated. It was negative because of the significant natural condition of Hormuz Strait and the impact of wind and extreme changes at sea level and the flow of incoming and outgoing.

A numerical modeling was performed for salinity changes under the influence of wind and thermohaline forces in Persian Gulf. The study showed seasonal salinity distribution and its changes under the influence of wind tension and using of a 3D hydrodynamic model, the thermohaline forces were analyzed (Hasan zadeh and Najar Khodabakhsh, 2002).

In another study, using a Coherence 3D hydrodynamic model, water circulation studied at 10 layers from surface to the seabed. In this model, the meteorological data over the past 54 years on a daily mean basis was implemented, and four main components of tide M_2, S_2, K_1, and O_1 were applied in the model. The aforementioned model on a daily basis calculated and simulated the current pattern from the surface to the seabed based on baroclinical exchange between pressure gradients and density gradients (Sadri Nasab, 2010).

Yazdani and Torabi Azad (2006) analyzed the coastal currents within Astara and Bandar Anzali coasts, and the features of the coastal currents at Southern Caspian Sea. A numerical method and FORTRAN programming simulated the changes due to the seasons. The study results showed that the mean value of coastal current speed at areas close to the Southern Caspian Sea had the maximum amount in winter and the minimum amount in fall.

Thoppil and Patrick (2012) carried out a study on the currents in Persian Gulf and stated that the

Iran's coastal currents move towards the North-West and from Hormuz Strait moves along the Northern boundary zone by a speed of more than 10 cm per second, and a current flows towards the Southern part of the gulf. Most of these currents before being under the influence of Western winds are created by pressure gradients. Except for the Hormuz Strait along the coasts of Iran, the impact of tide on these circulations is very insignificant. The circulation and the mass structure of water in Persian Gulf were the topic of several previous studies and they were conducted based on the hydrodynamic numerical models or spectral models with horizontal location differentiation (20-25 Km).

In another study conducted by Kampf and Sadri Nasab (2006), the results showed that over fall and winter, the simulations had a clock-wise movement of a consistent current pattern to the north of Persian Gulf that consists of a consistent coastal jet along the coast of Iran towards the South-East with the maximum speed of 10 cm/s.

2. Material and Methods

Given the conducted studies and the observation of temperature and salinity changes along the depth of the body of water in related works, it seems that 3D models are more optimal. Therefore, in the present study, numerical model MIKE3 from MIKE package is used. This software package developed in Denmark hydrodynamic institution (DHI) and has a trade aspect. This module (MIKE3) consists of a correlation equation and three models of movement size that are solved at three aspects. MIKE3 considers changes of tide, currents caused by wind, currents caused by tide, and sea currents along with other hydrographic conditions such as the impact of density changes because of disproportional spread of salinity and temperature. At MIKE3 based on the equation presented by the UNESCO, density is a function of the local temperature and salinity. Because of the impact of the rivers, water inlets and outlets such as power stations, and water desalination plants lead to the changes of density of temperature and salinity. These issues can be considered as well or spring in simulation that for both of them there is a possibility of imposing different physical changes.

MIKE software consists of different simulation models to simulate different hydraulic and hydrodynamic phenomena at 1, 2, and 3 dimensional formats. Hydrodynamic model MIKE3 FM that also has the model of salinity and temperature was implemented to model the salinity behavior. Networking of the numerical model MIKE3 FM in a 3D model has been shown in figure 1.

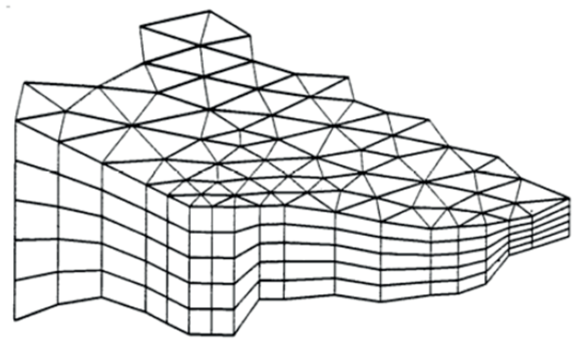

Figure 1. Networking at MIKE3 FM model

Environmental values related to the temperature and salinity, have been implemented based on the other articles and different curve diagrams. Environmental salinity in grams and the temperature in centigrade were introduced to the model as follows (Table 1). Since temperature and salinity data as the input parameters of the model, are changeable over different seasons, therefore, the modeling was performed for four consecutive seasons that would be displayed in the following part.

3. Results and discussion

3.1. Baroclinic current modeling in spring 2014

In this research, the levels of depth are divided by sigma layering method into 10 layers. Because of the temperature and salinity changes at different seasons, the model is used for different seasons. In

Table1. Input features at density current model

Baroclinic data	Winter	Spring	Summer	Fall
Surface Temperature (°C)	21	23	31	31
Medium salinity (PSU)	38.56-40.08	37.26-40.88	37.85-40.39	39.47-40.59

most seasons, salinity has very little changes and this is why the temperature has lots of changes and in winter and summer the changes of temperature reaches to more than 10 ºC. Given the fact that the density of the sea is a function of different parameters and especially salinity and temperature in these two seasons, the changes of density is very considerable. The Persian Gulf topography and the hydrography of the coastal line of the Persian Gulf influence the changes of temperature, density, and currents. Because of the low depth of the coastal line, the impact of sunlight is more into the sea and therefore, the depth temperature and the seabed temperature are higher. But physical parameters pattern at seabed is influenced by the general currents of the Persian Gulf. Given the fact that the purpose of the present study is to analyze the density current pattern in North of the Persian Gulf. In order to see physical parameters changes in Persian Gulf and particularly in the Northern part, some sections have been cut out and a number of parameters along the depth of these vertical profiles on Persian Gulf and parallel to the coast of the Persian Gulf have been displayed (Figure 2)

The speed of the current at surface layer at reflow is around 25 cm/s and at the time of tide up to 35 cm/s and at the time of spring, tide moves towards the North-West and at the time of Neap, tide moves towards the Oman Sea and the South-East of the Persian Gulf (Figure 3).

In terms of density changes, it still expected that the density is about 1020 kg/m^3. In different seasons, considering the changes of temperature and salinity, the changes of density are significant.

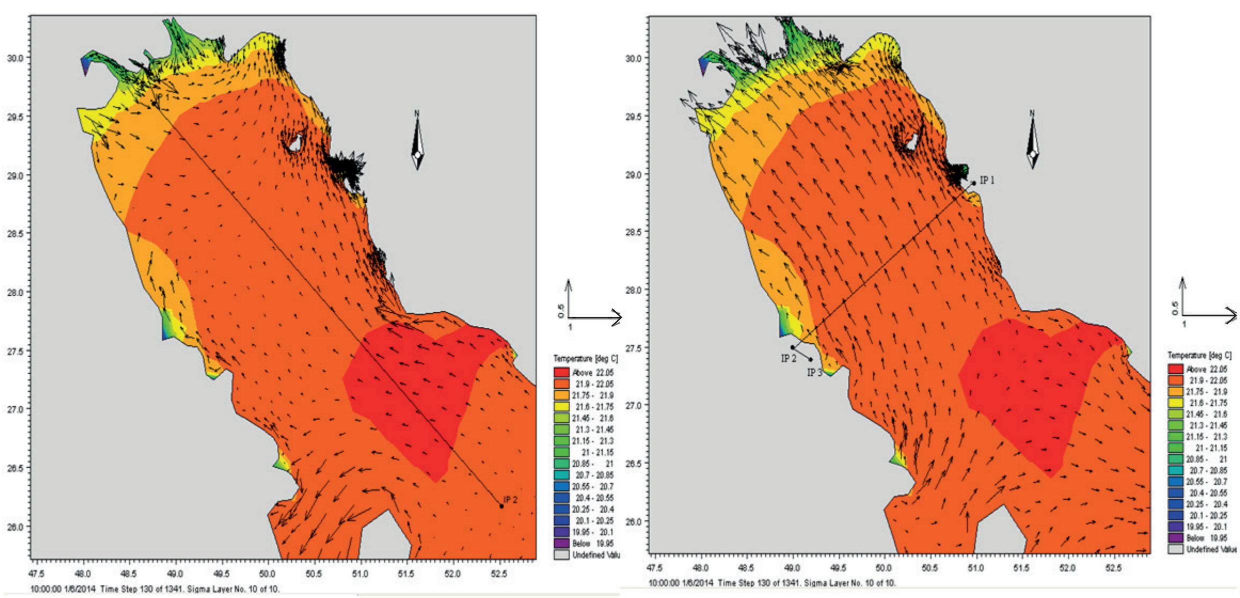

Figure 2. Longitudinal section (left) and cross section (right) of the North of Persian Gulf

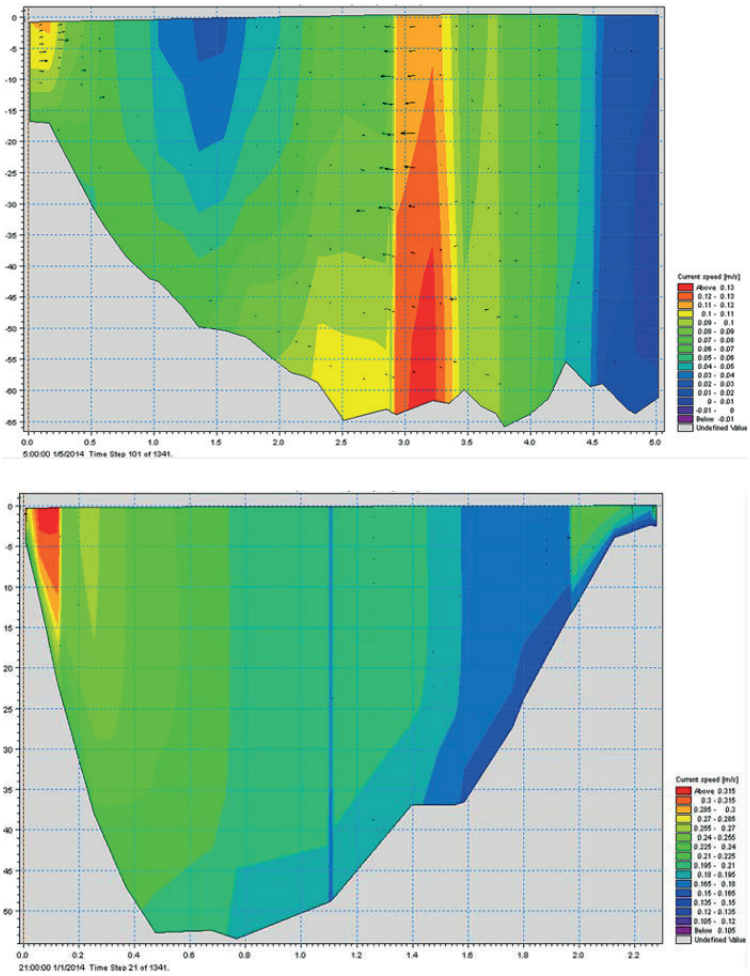

Figure 3. Current velocity distribution along the longitude of the Persian Gulf at the time of difference between reflow and tide (up), and The profile of current velocity changes along the lateral section at the Northern part of the Persian Gulf (down)

In summer, when there is more rise of temperature and there is less rainfall, which accompanies the rise of salinity, therefore, the density of the sea water increases up to 1029 kg/m^3. In winter, it reaches to 1020 kg/m^3. The mean value of density in Persian Gulf is around 1024 kg/m^3 (Figure 4).

In spring, temperature differences between depth and surface level is around 2 °C, and temperature variation in spring in Persian Gulf at surface section is around 22 °C. Temperature changes in the middle of the Persian Gulf are almost constant, and the temperature values reduce towards the coastal areas. The process of the changes at seabed and surface are almost the same (Figure 5).

3.2. Results of baroclinic current modeling in winter 2014

Given the large mass of different parameter outputs, and the similarity of many parameters such as salinity, density, and the velocity of the current, the parameters are not presented

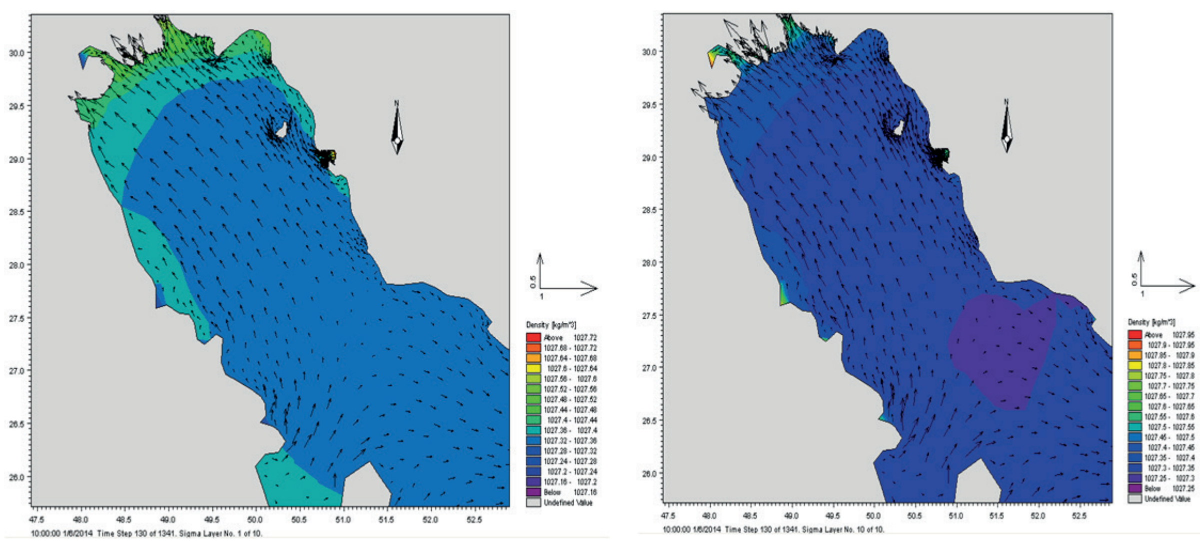

Figure 4. Results of density changes at surface (left) and seabed section (right)

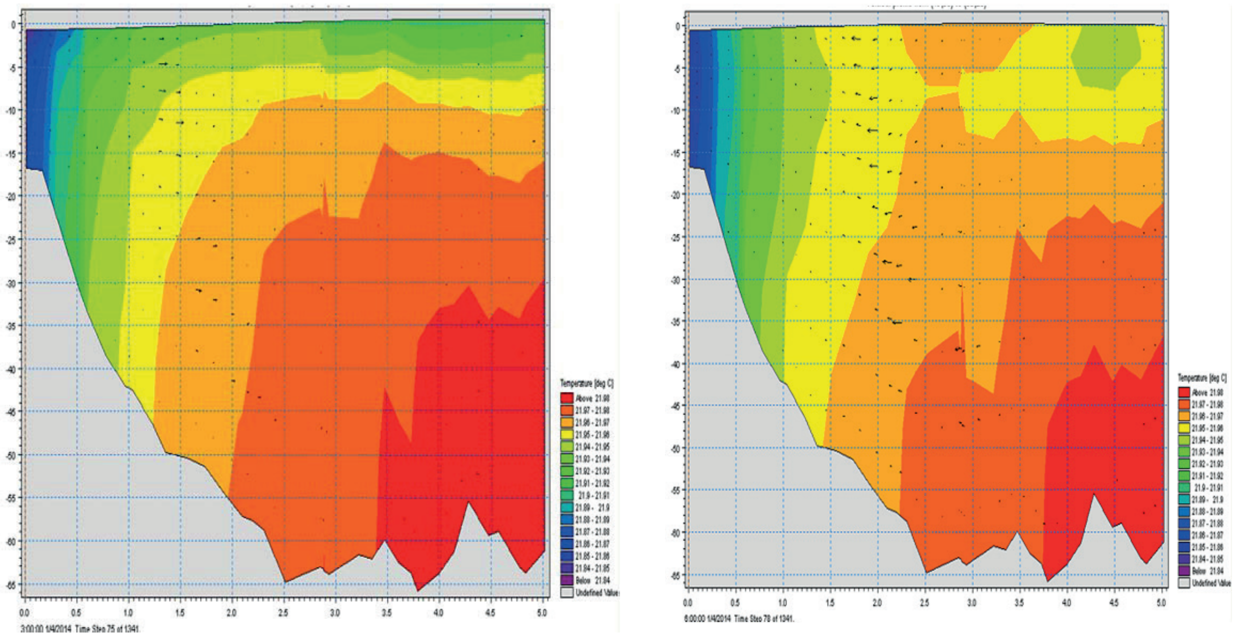

Figure 5. Temperature changes along the longitude in the Persian Gulf at the time of reflow (left), and tide (right)

in a seasonal format, and only a comparison at two rainfall seasons are represented. The evaporation are also considered in two seasons; low-water, and high-water, which comprehensively represent physical parameters changes in Persian Gulf. Therefore, for every parameter, the changes at surface and seabed or a particular geographic location is extracted and analyzed.

The surface temperature in the Persian Gulf in two seasons of winter and summer has two different patterns. In winter, the surface water temperature in the Oman Sea and Hormuz Strait is the least and in deeper areas, it is less and towards the coastal areas and the low-depth areas there is a rise of temperature. In contrast, in summer in Hormuz Strait and Oman Sea the surface temperature has the maximum value and towards the low-depth areas the surface temperature reduces (Figure 6).

Temperature changes pattern at bottom level of Persian Gulf show that in winter, the deep water has a less temperature and towards the coastal line there is a rise of the temperature. In Hormuz Strait

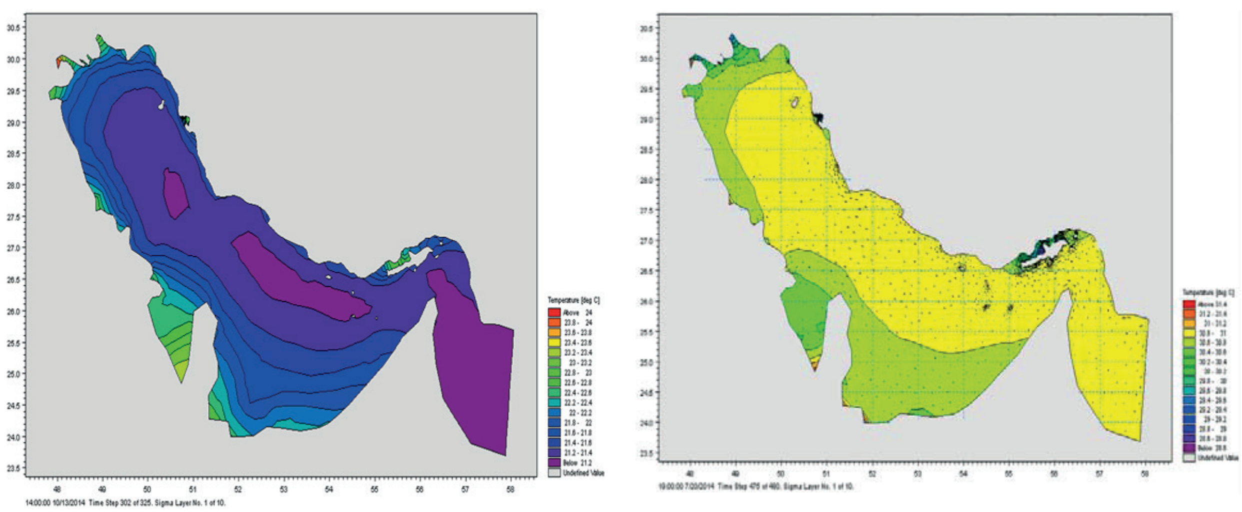

Figure 6. Results of temperature changes at surface section in winter (left) and summer (right)

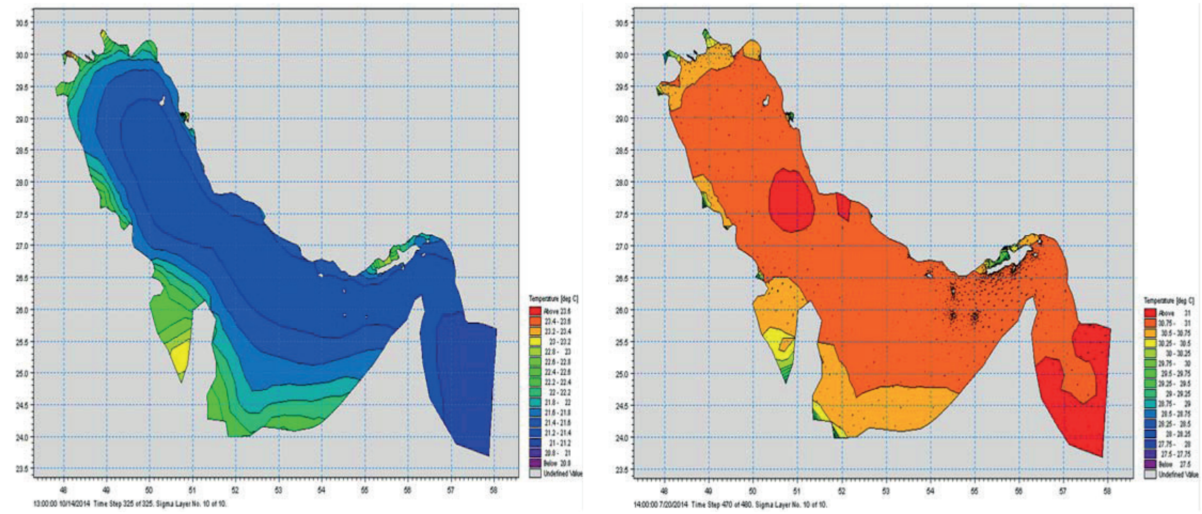

Figure 7. Results of the temperature changes at seabed section in winter (left) and summer (right)

and Oman Sea, there is always minimum temperature of the seabed. In the inlets, such as Khur Musa, Bushehr channel, Arvand rud, and the low-depth areas, the bed water temperature is more. In summer, this process is quite vice versa that is in the Oman Sea and Hormuz Strait the bottom water temperature is maximum and also in the middle part and deeper part towards the inlets and the low-depth areas, the temperature of the seabed water reduces (Figure 7).

Among the physical parameters of seawater, salinity always have insignificant changes at different seasons and places and the scale of salinity changes all over the year reaches to 1 or 2 units. Therefore, to display the salinity changes pattern small-interval categorizing was implemented. Salinity changes despite little fluctuations, such as temperature parameter in summer and winter, have different patterns. Salinity changes across the Persian Gulf in winter are so that in the Oman Sea and Hormuz Strait, and the deeper part of the Persian Gulf the surface, salinity is the maximum, and at the low-depth coastal line and the inlets, the salinity is more. Generally, the Iran's coastal areas have higher surface salinity level in winter. In summer, this process is vice versa, and the surface salinity in the Oman Sea, Hormuz Strait, and the deeper areas of the Persian Gulf is low and the salinity increases

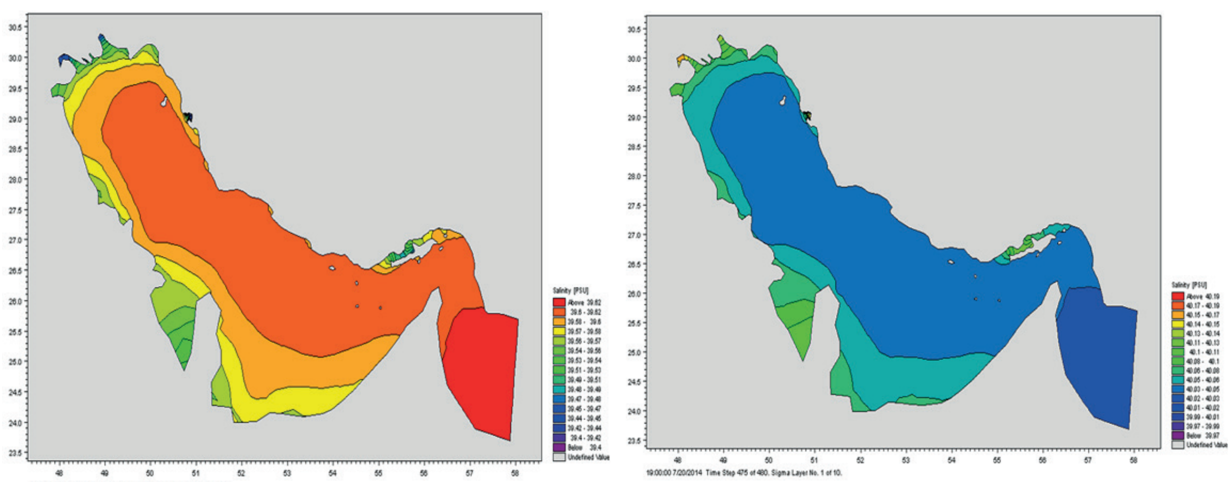

Figure 8. Results of the salinity changes at surface section in winter (left) and summer (right)

towards the inlets and low-depth areas (Figure 8).

In terms of salinity, at seabed section of the Persian Gulf there are two opposite and contrasting patterns between winter and summer patterns. In winter, the salinity at seabed section of deep areas is more and in summer, it is less at deep areas. In winter, in the Oman Sea and Hormuz Strait, and the middle part, the salinity of the seabed section has the maximum value and in the coastal line and the inlets, it is the least. This process is vice versa for the summer (Figure 9).

Investigating the surface current counters shows that in contrast to the salinity and temperature parameters, the counters appear along the vertical current counters on the Persian Gulf, and the movement process within the Persian Gulf is not dependent on depth counters. Since the tide causes the dominant current in the Persian Gulf, the current pattern was different from surface to the bottom (Figure 10).

Current velocity at seabed section is variable in different seasons, but considering the fact that in the Persian Gulf, the half-day tide current pattern is mixed every 24 hours. A different tide pattern occurs in the Persian Gulf and its maximum and

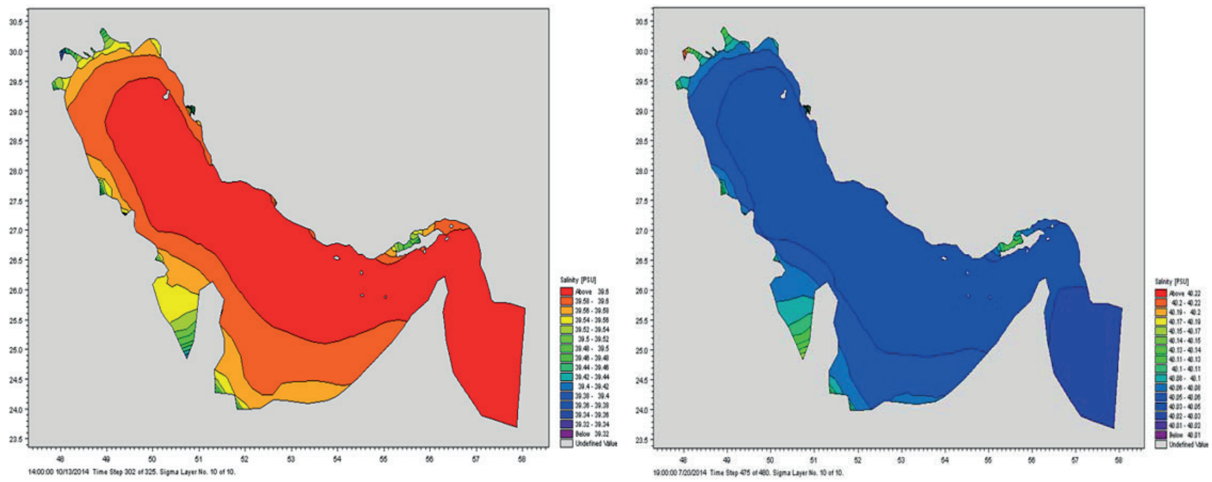

Figure 9. Results of the salinity changes at seabed section in winter (left) and summer (right)

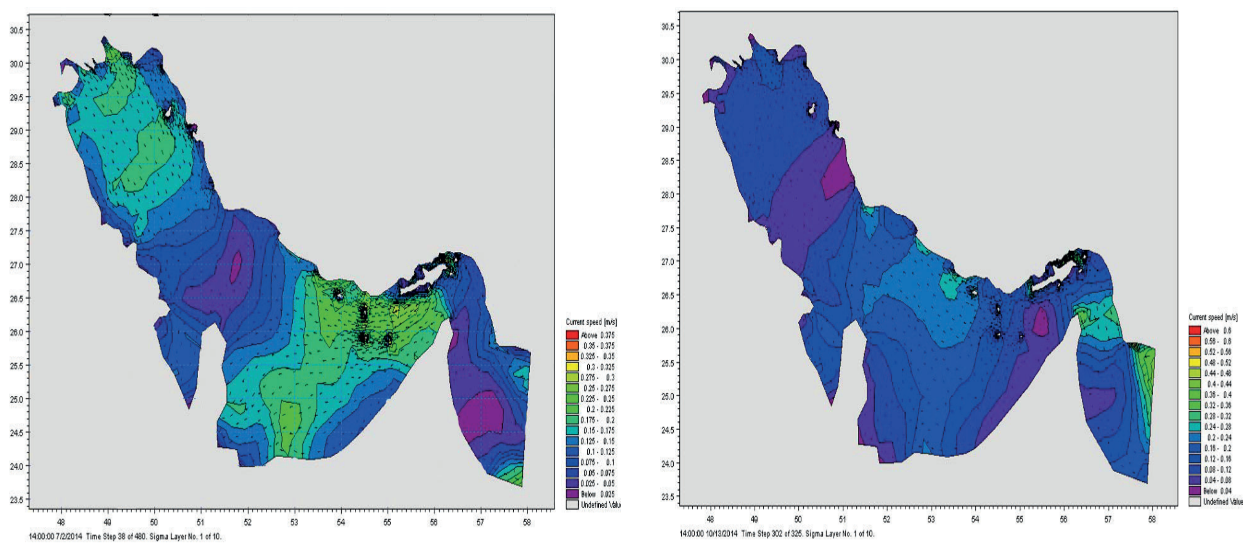

Figure 10. Results of the current velocity changes at surface section in winter (left) and summer (right)

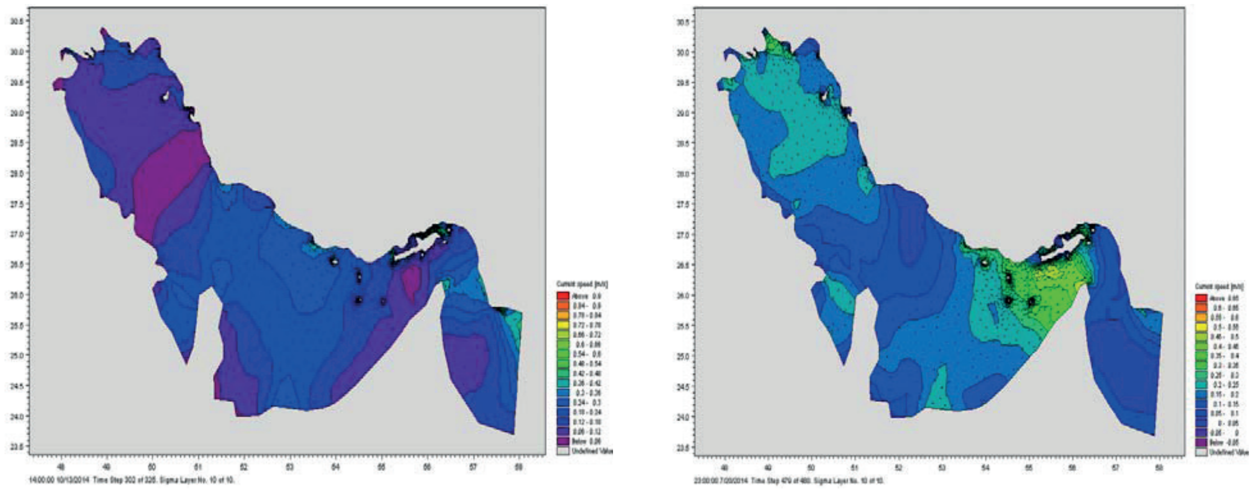

Figure 11. Current velocity changes at seabed section in winter (left) and summer (right)

minimum amount happens at the beginning and the middle of lunar month because the largest gravity between moon and the earth does not belong to a particular season. In the same line and only because of change of salinity and temperature changes in different season water with different density enters into the tide currents of the Persian Gulf and moves by the tide cycle. In this moving current inside the Gulf and the inlets, the density current is created by the change of temperature and salinity. Consequently, because of density differences before and after the Hormuz Strait and very little difference between different layers of water in the Persian Gulf region influences the regional current condition to a small extent (Figure 11).

3.3. Results of physical parameter modeling along three sections in the Persian Gulf

So far, different patterns of the parameter changes in the Persian Gulf were analyzed laterally and longitudinally. At this part, the parameters changes pattern along the Persian Gulf were evaluated. Therefore, along the Persian Gulf from the North to the Hormuz Strait, a number of longitudinal sections were extracted in the following part. Here,

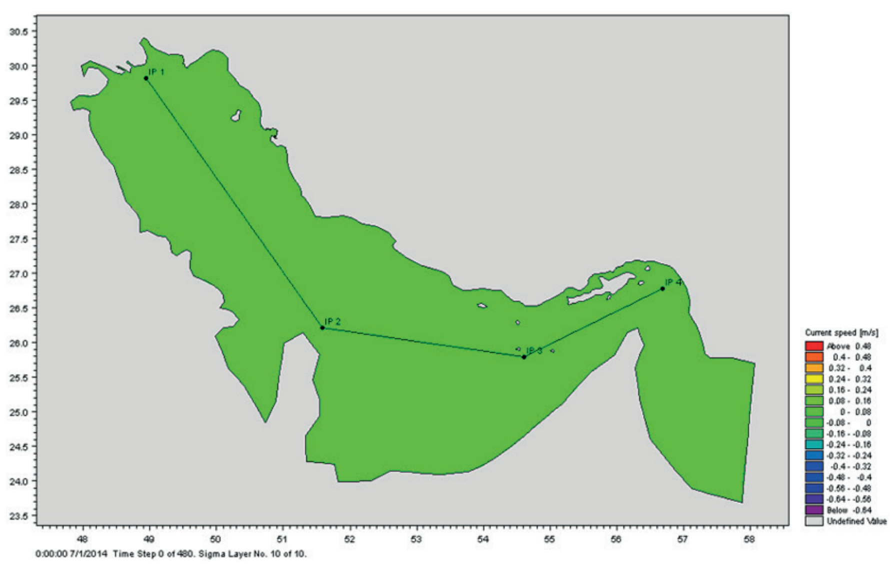

Figure 12. Three longitudinal sections displaying along the Persian Gulf for comparing the physical parameters

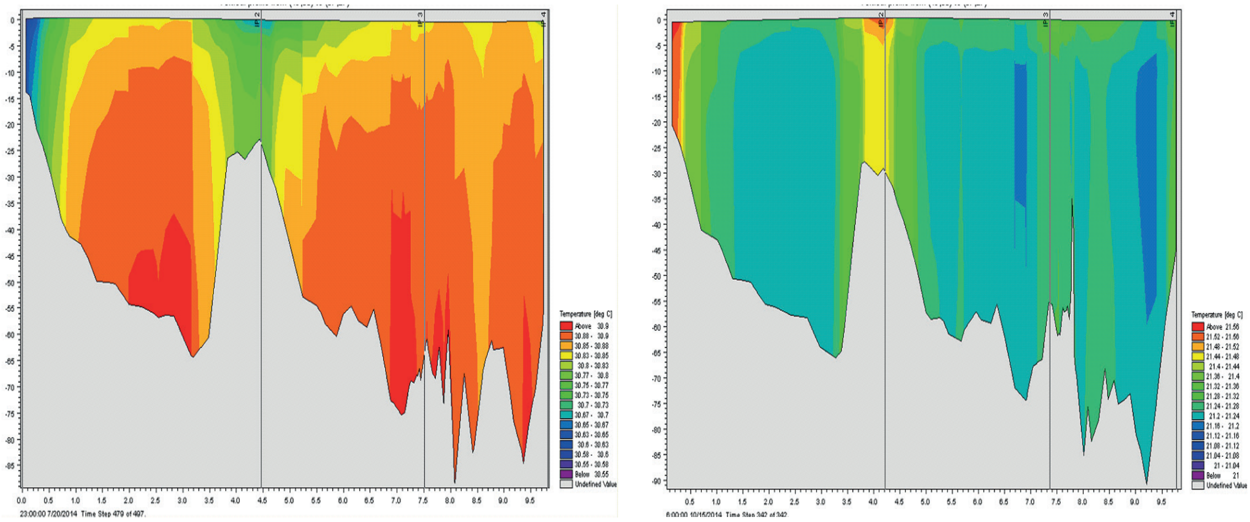

Figure 13. Temperature parameter displays along the three longitudinal sections in the Persian Gulf in summer (left) and winter (right)

three longitudinal sections are analyzed, respectively, the left section; the North of the Persian Gulf, the middle section; the middle of the Persian Gulf, and the right section; the Eastern part ending in Hormuz Strait (Figure 12).

Vertical temperature profile shows changes in summer when the maximum temperature is at seabed section, and reduces towards the surface layer. In winter, temperature changes are so that the maximum temperature is at surface level and the minimum temperature occurs at seabed section. The temperature difference between surface level and seabed section reaches to 1 °C (Figure 13).

Figure 13. Temperature parameter displays along the three longitudinal sections in the Persian Gulf in summer (left) and winter (right)

In terms of the salinity parameter, almost all levels have the same values of salinity. But by a microscopic look, it is detected that salinity is more in summer at the seabed section. Salinity parameter is also the same in winter and the salinity is more at the seabed section (Figure 14).

Given the fact that density changes are caused by temperature and salinity changes, the density

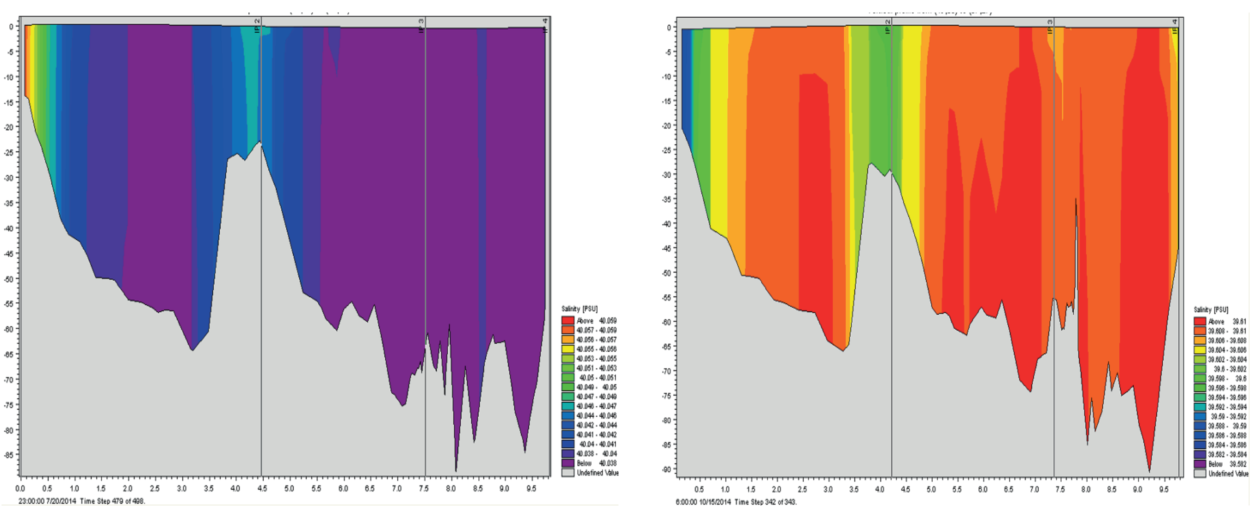

Figure14. Salinity parameter displays along three longitudinal in the Persian Gulf in summer (left) and winter (right)

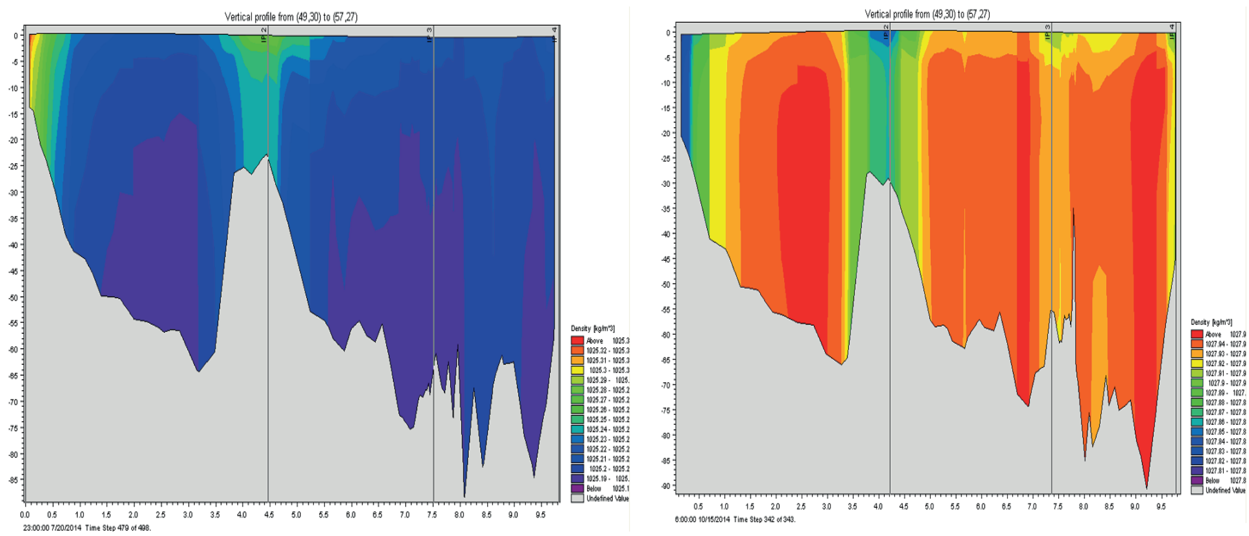

Figure15. Density parameter displays along the three longitudinal sections of the Persian Gulf in summer (left) and winter (right)

changes function is a pattern of temperature and salinity. But by considering the fact that salinity is almost stable in summer, the vertical density profile is a function of vertical temperature profile. Considering the fact that the temperature is higher at the seabed level in winter the density of the water is less at seabed level. Density in winter is nearly constant and there is no significant difference along the vertical direction. In a comprehensive and general look, it is obvious that the seabed density is always more (Figure 15).

The velocity of the current in summer is more at surface layers. The east factor current velocity that moves towards the Hormuz Strait is twice more, in comparison with the North way current velocity which means that most of the current moves inwards and outside the gulf and the current does not occur vertically on Iran or the Southern coasts of the Persian Gulf. In winter, studying the current velocity factors towards the North and the East, showed that towards the East the current is the dominant one, and it is several times more than the North direction. These results show that the velocity is mostly towards the length of the Persian Gulf and the current velocity is very low

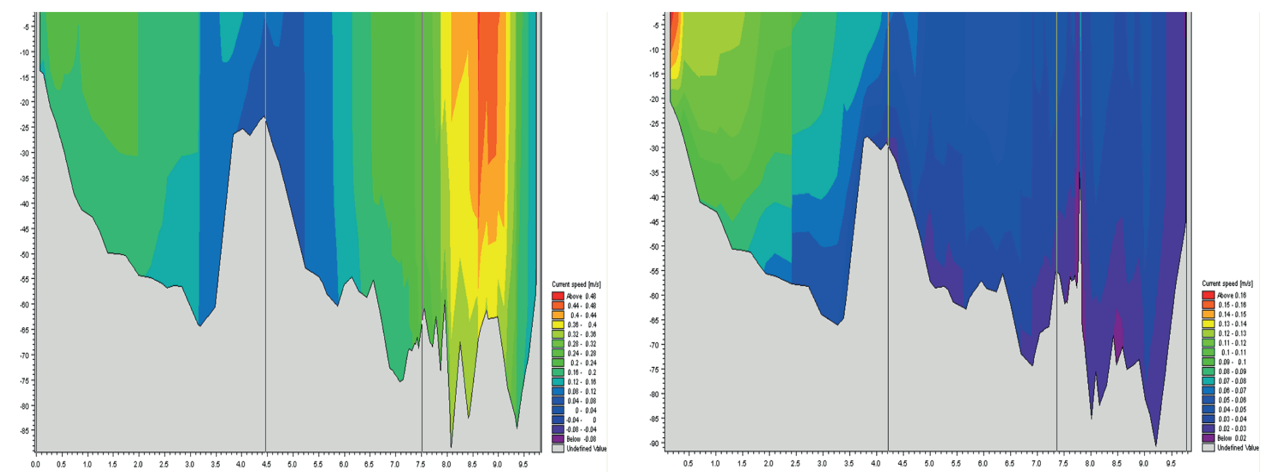

Figure 16. Current velocity parameter displays along the three longitudinal section of the Persian Gulf in summer (left) and winter (right)

as the vertical current on the Persian Gulf. In all cases, the current velocity of the seabed section is more. In the Hormuz Strait region, the velocity of the seabed and the surface level become closer. The velocity of the vertical layer in winter is zero which means that in winter the difference between the surface layer and the seabed layer occur slowly. This is because of the fact that geo metric changes of the temperature, salinity and as a result of that density at different layers of surface and seabed section are insignificant and therefore, no significant difference of density happens in the Persian Gulf and consequently the vertical layer current velocity is very low (Figure 16).

Conclusion

By observing the vertical profile of physical parameters along the three sections of the Persian Gulf from Khuzestan province to the Hormuz Strait, in two seasons of winter and summer, the following results obtained:

- The maximum temperature in summer in the Persian Gulf is around 30.9 ºC degrees near the seabed section and in winter 21.56 ºC near the surface level.
- The maximum salinity in summer in the Persian Gulf is around 40.05 PSU near the surface and in winter 39.61 PSU near the bottom section
- The maximum density in summer in the Persian Gulf is around 1025 kg/m^3 and in winter around 1027 kg/m^3 near the seabed section
- The tide current velocity along the longitude of the Persian Gulf is several times stronger than current velocity at lateral width of the Persian Gulf.
- The surface temperature in the Persian Gulf in two seasons, winter and summer, has two opposite patterns compared to each other. In winter, the surface water temperature in the Oman Sea and Hormuz Strait is the least and at deeper areas, it is low and there is a rise of the temperature towards the coastal areas and the low-depth areas. In winter in opposite of Hormuz Strait and the Oman Sea, the surface temperature is the maximum one and towards the low-depth areas the surface temperature decreases.
- Salinity changes at the Gulf level in winter is so that at the Oman Sea and Hormuz Strait, in deeper areas, there is maximum salinity level, and at the coastal line, the low-depth areas, and the inlets, there is more salinity. Generally, the coastal areas of Iran have higher salinity level in winter. In summer, this process is opposite, and the surface salinity in the Oman Sea, Hormuz Strait, and deep-water areas are less and the salinity parameter increases towards the inlets and low-depth areas. In terms of the salinity at seabed, section in the Persian Gulf there is also an opposite pattern. In winter at seabed, section of the deep areas it is more and in summer in deep areas it is less. In winter in the Oman Sea, Hormuz Strait, and middle part of the Persian Gulf the seabed section is the maximum and the coastal line and inlets are the least. This process is opposite for the summer.

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