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Journal of Marine Science
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ARTICLE

Study of the Effective Factors on Shelf Currents in the Southern Caspian Sea

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ARTICLE INFO

Article history
Received: 22 February 2019
Accepted: 26 February 2019
Published Online:30 April 2019

Keywords:
Caspian Sea
Shelf currents
Wind
Low-frequency motions
Kelvin waves

ABSTRACT

The current and wind records and the physical parameter structures such as temperature and salinity in the southwestern part of the Caspian Sea adjacent to Anzali Port were investigated from November 2004 up to the end of January 2005. Results show that, despite the existence of relatively weak winds along the coast in the area, the measurements indicate strong long shore currents. However, when heavy wind tension is observed in the area, then strong currents are also present, which - from the perspective of direction – also have good coordination with the wind. The direction of dominated currents was parallel to the coast from the west to the east. In most cases, the flow rate was identical from the surface to the seabed, and in this condition - because the values of the measured temperature points were almost identical-barotropic currents were present. However, in the autumn at some region, a significant difference was observed between the surface currents and subsurface currents due to temperature differences that affected the density and caused the creation of barocilinic currents. Due to the high velocity of currents compared to wind velocity, and the intense slope of the coast and low-frequency movements in the area, we can hypothesize the existence of motions such as Kelvin waves and conclude that the effect of the wind compared to the other factors of the coastal current in the area was weaker.

1. Introduction

The Caspian Sea is the largest inland body of water on the planet, with a surface area of 379000 km^2 and a volume of 78000 km^3 [1]. The Sea can be divided into three distinct basins: a northern (covering 80000 km^2), a middle (covering 138000 km^2) and southern (covering 1648400 km^2) [2,3]. There are about 130 rivers that are connected to the Caspian Sea, and most of them have small discharge rates. The largest inflow of fresh water belongs to the Volga river, accounting for about 80% of the climatological mean river discharge of 250 km3yr-1 [4]. The general circulation in the Caspian Sea is reported to be anti-clockwise (cyclonic) based on both indirect estimates of currents [5]. The isolated water and its inland position of the Caspian Sea are responsible for many of the important outer thermohydrodynamic factors, specifically the heat and water fluxes through the sea surface, river runoff for the sea level variability, formation of its 3D thermohaline structure, and water circulation [6].

Spatially and temporally variable currents in the Cas-

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DOI: https://doi.org/10.30564/jmsr.v1i1.550

pian Sea are a consequence of the elongated geometry and strong topography of the basin, influenced by variable wind forcing and baroclinic effects. Investigations done from the end of the 19th century until the 1950s show that the overall general circulation of the Sea is cyclonic, even though strong sea current variability exists [5,7]. In the years 1935–1937 [8,9], six instrumental surveys were done on the western coast of the middle Caspian basin. The surveys indicated that mostly southward currents flowed alongside the western coast of the middle Caspian basin that were influenced by wind-driven currents near the surface.

The aim of this study was to investigate the shelf current features and the role of wind, density and other forces in formation of surface and subsurface currents. In this paper, data measurements were analyzed and conclusions are presented.

2. Materials and Methods

2.1 Study Area

From November 2004 up to the end of January 2005 the current – aligned vertically to the cost, up to a depth of 200 m was measured in the southwestern area of the Caspian Sea between the estuary of the Sefidrood river and Anzali port at the width of the continental shelf. In order to measure the currents three stations were set up with three mooring current meters (RCM9-MKII). The first mooring station (at 20 m depth) held two devises at 5 and 18 m depth; the second station (at 50 m depth) held two devises at 5 m and 47 m depth; and the third station (at 200 m depth) held three current measuring devises at 3 m, 58 m and 122 m (Fig. 1).

In autumn (October) and winter (January) the researchers also took CTD measurements following the major axis of the current measurements alongside and in the direction of the moorings at the 17 stations (which were at a distance of 1000 m from each other).

2.2 Computation of Salinity

UNESCO has established empirical equations for the computation of salinity and density from CTD data [10,11]. However, these equations are limited in their validity for only water that has an ionic composition of standard sea water, so these equations cannot be used for the Caspian Sea water [12]. In laboratory experiments done by Millero and Chetirkin [13] an empirical equation for the Caspian Sea water was formulated by taking water samples from the southern part of the Caspian Sea adjacent to Iran. This equation was rendered valid only at surface pressure in a specific temperature range. Later Peeter et al.[12] adapted the experimental equations (salinity and density) according to the ionic composition of the Caspian Sea waters from water samples taken previously from the Sea [14]. Peeter et al.'s surface water density computation - based on their equation of state – was similar to Millero and Chetirkin's computation[13]. Therefore, the salinity calculated from CTD data by UNESCO standard processes[12] is less than the salinity taken from the chemical methods. Hence, by using a modification factor of 1.1017, the researchers were able to arrive at an ideal agreement between the amount of salinity (calculated from CTD data and the UNESCO formula) and the salinity (calculated from the chemical method):

$$\text{SalinityCas} = 1.1017\ \text{Salsea} \quad (1)$$

Where in 1.1017 is the correction factor, Salsea is computed salinity using the UNESCO equations, and SalinityCas is the corrected salinity for the Caspian Sea water. The equation is free of pressure, temperature, and salinity ranges and is versatile enough to be used for different conditions and depths.

Figure 1. Caspian Sea and position of the study area

2.3 Principal Component Analysis

Principal component analysis (PCA) can be used to identify data patterns and pinpoint their similarities and differences[15]. Theoretically, PCA allows data rotation that is placed onto a set of orthogonal axes with extremized variation[16]. PCA is supposed to decrease the number of variables of interest into smaller component-sets[16]. PCA analyzes all the variances in the variables and restructures

DOI: https://doi.org/10.30564/jmsr.v1i1.550

them into a new set of components equivalent to the number of original variables.

2.4 Spectral analysis

Spectral analysis was used to partition the variance of a current time series as a function of frequency[17]. Spectral formulas were derived to calculate the space-time (wave number frequency) spectra using time spectral techniques such as the lag-correlation method, the direct Fourier transform method and the maximum entropy method [18-20]. To obtain the power spectrum of the measured currents and to distribute the total variance over a range of frequencies the Fast Fourier Transform was used. The highest frequency (i.e., the Nyquist frequency ($fN = 1/2\Delta t$), which can be resolved with a sampling interval of one hour, is 0.5 cph. The rotary spectra were formulated by Fofonoff [21]. The rotary spectral analysis resolves a velocity vector into clockwise or negative sense (indicated by negative frequencies) and anticlockwise or positive sense (indicated by positive frequencies) components.

3 Results and Discussion

3.1 Wind and Current variability

According to Fig. 2, the values of longshore parallel currents along the water column in the first and second stations are very close and the difference between the surface and deep currents are slight. However, the currents' velocity from the coast to the relatively deep areas has been rising significantly, which can be caused by friction of the bed in coastal areas. The currents' velocity value of the surface, subsurface, and bottom (or seabed), with a 200 m depth, are significantly different and the currents' velocity value at bottom (or seabed) has reduced considerably. At this station, the currents' velocity is stronger in fall compare to winter. In the winter the velocity difference between the layers, especially the surface and the subsurface layer, is reduced considerably, so that the currents' velocity from the surface to depth is approximately the same value. Figures 3 and 4 show the relationship between daily wind speedmean and surface current speed mean. There was a significant difference between the maximum mean value of daily long shore parallel currents' velocity at this period for stations 1 to 3 with the value of 65.4 cm/s, 84.6cm/s and 95.7cm/s, respectively, compared to the maximum mean value of daily currents' velocity perpendicular to the shore for stations 1 to 3 with the value of 18.5 cm/s, 12.3 cm/s and 10.9cm/s respectively.

The moving averages techniques were used in Fig. 5 and 6, and the main advantages of moving averages are that they smooth the data and thus determine the current trend. According to these figures, the existence of strong long shore currents that flow parallel to the shore can be observed in the absence of strong winds flow parallel to the shore. Also, the wind flow along the vertical was stronger than the wind flow parallel to the shore, but the currents' velocity was much weaker in this direction. Considering Fig. 3 to 6, the surface currents perpendicular to the shore in stations did not have that much linkage or coordination and there was not much similarity between the long shore currents that flow parallel and perpendicular to the shore. Also, no relationship between the currents perpendicular to the shore and the wind flow perpendicular to the shore has been observed. The direction of long shore currents that flow parallel to the shore in stations - most of the time - was in relatively high coordination with the wind, which can be observed in Fig.7. This figure also shows the results of the principal component analysis (PCA). At the three stations for current measurement, in most cases the flow direction of the long shore currents parallel to the shore are from the east to the west. According to the mentioned figures, in particular times when the effect of winds parallel to the coast was stronger, the influence of the wind on the long shore currents is quite obvious. However, given the high velocity rate of long shore currents parallel to the shore, relative to the wind speed values(parallel to shore) and considering that typically the velocity of the currents' wind driving force is about 3 percent of the wind velocity, strong correlation between wind and surface currents can not be observed at the stations.

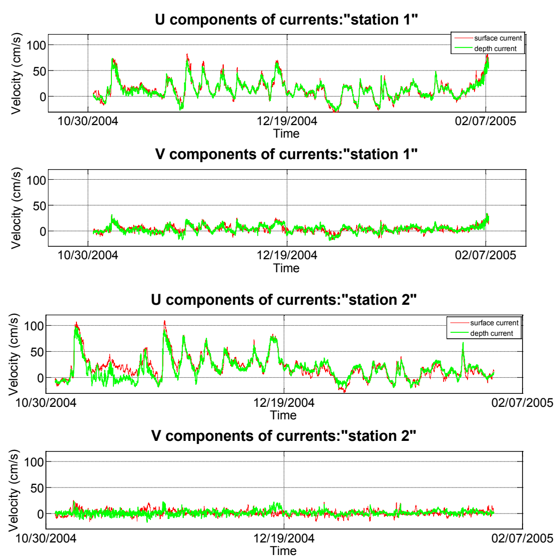

Figure 2. Top: Current velocities at surfaceand subsurface (station 1), Middle:Current velocities at surfaceand subsurface (station 2), Bottom: Current velocities at surface, subsurface and depth layers (station 3)

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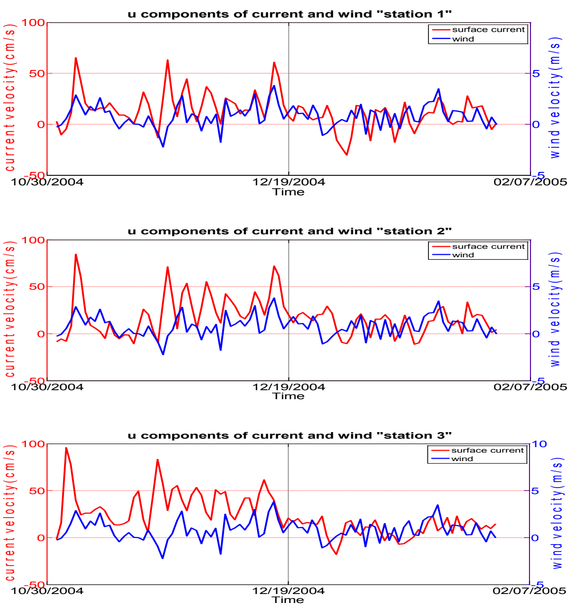


Figure 3. Average daily longshore surface current velocity and wind

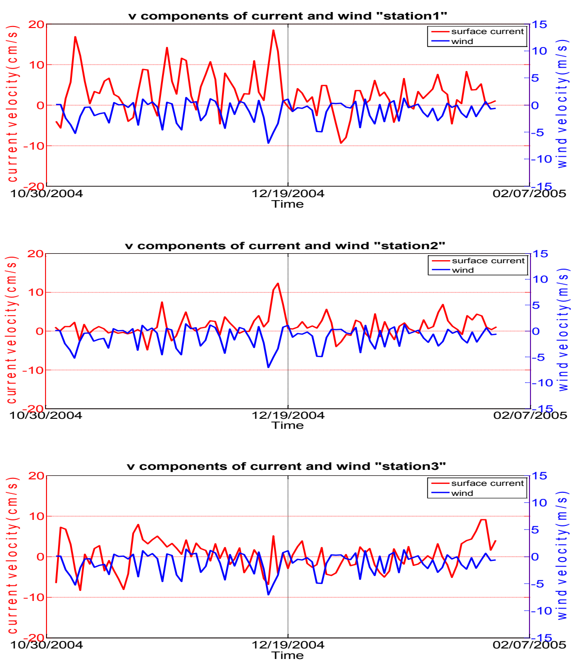
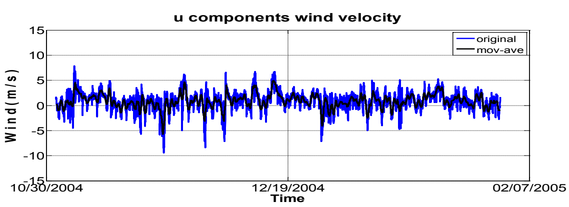


Figure 4. Average daily cross-shore surface current velocity and wind



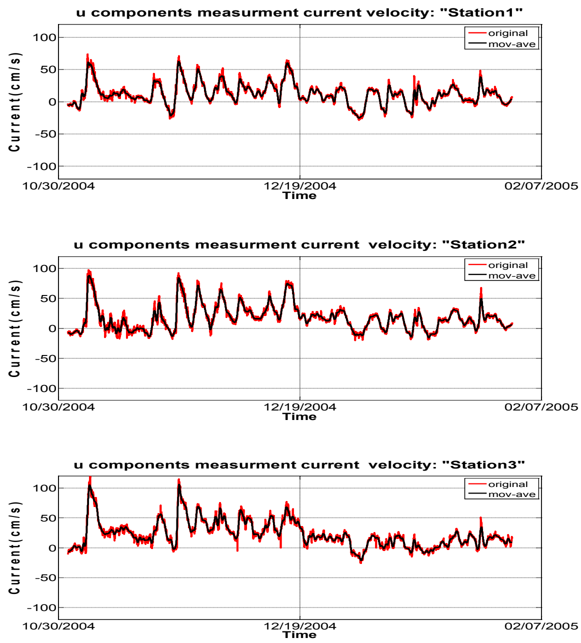


Figure 5. Longshore surface current and wind velocities at surface layer (blue line: original wind, red line: original current,black line: moving average)

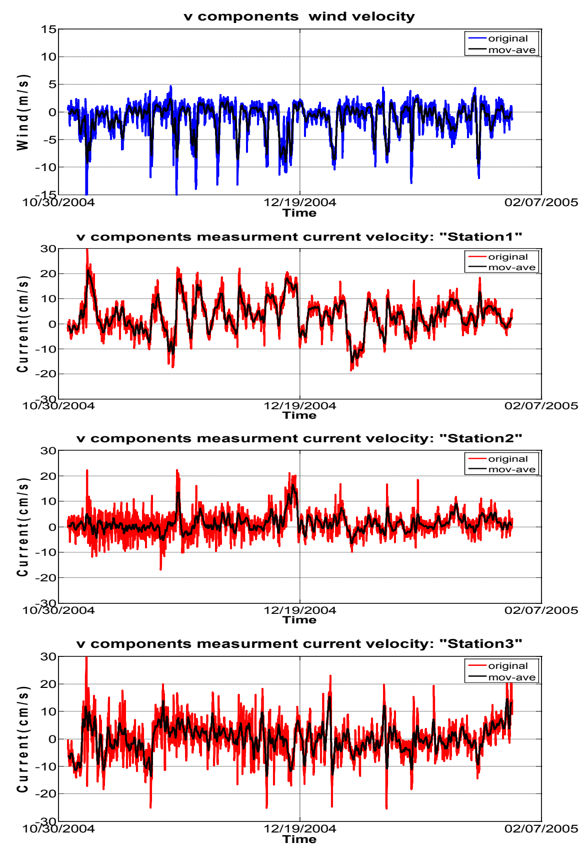


Figure 6. Cross- shore surface current and wind velocities at surface layer (blue line: original wind, red line: original current, black line: moving average)

 DOI: https://doi.org/10.30564/jmsr.v1i1.550

3.2 Structure of Temperature and Salinity

Figures 8 and 9 show the vertical temperature and salinity structures of the data taken from the 17 stations in autumn and winter. In autumn there was a thick surface layer due to weather temperature decrements and the thermocline was around 30 to 40 m. In the width of the layer, temperature change was 7°C, with the upper layer at about 19°C, and the lower level at about 11.5°C. In winter, field data showed (Fig. 9) no season thermocline, but there was a uniform temperature (9.5°C to 10.5°C) up to a depth of 100 m (Fig. 9). Little vertical gradient saline change occurred in this coastal region during the four seasons (Fig. 8 and 9). Due to the structure of the vertical density, the slight saline change was in agreement with temperature change.

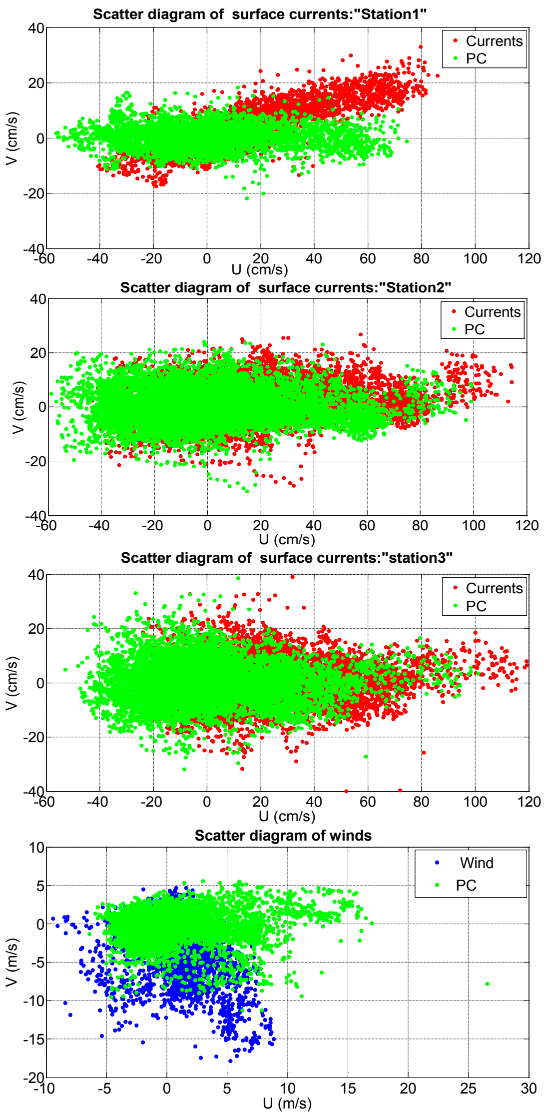


Figure 7. Scatter diagrams of surface current and wind (red scatter: current, blue scatter: wind, green scatter: PC)

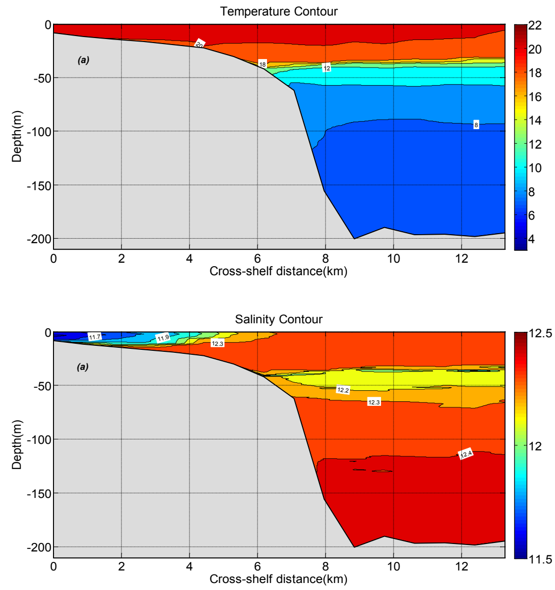


Figure 8. Vertical temperature (top) and salinity (down) structure in the study area in October (2004)

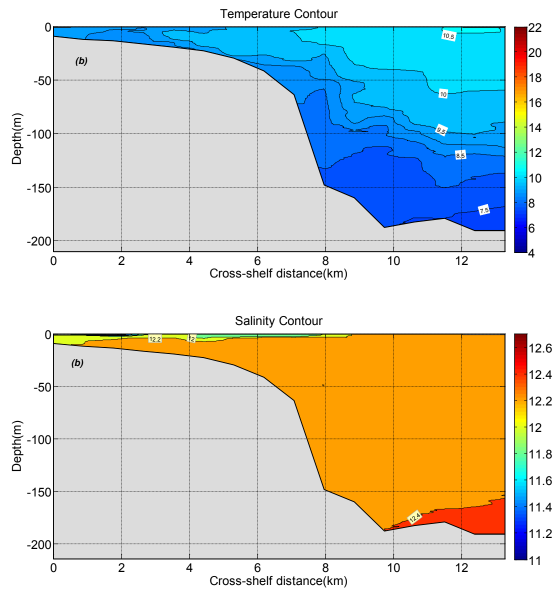


Figure 9. Vertical temperature (top) and salinity (down) structure in the study area in Januaury (2005)

Significant differences between autumn and winter existed in the vertical transect of velocity. Current velocity measured in this area 3 m from the surface and subsurface layer (58 m from the water surface) is shown in Fig. 2. The depth of these points in autumn on the upper and bottom layer is consistent with thermocline. We also saw significant decreases in current velocity in the subsurface layer when Significant differences between autumn and winter existed in the vertical transect of velocity. Current velocity measured in this area 3 m from the surface and subsurface layer (58 m from the water surface) is shown

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in Fig. 2. The depth of these points in autumn on the upper and bottom layer is consistent with thermocline. We also saw significant decreases in current velocity in the subsurface layer when compared to the surface layer (Fig. 2-bottom).In winter the thermocline layer vanished and surface and subsurface currents were about equal, concluding that this alteration in the current from surface to depth signals temperature change, and due to the vanishing of the winter thermocline layer, the alteration in temperature in the water column was roughly insignificant and consequently current velocity change in this water column will be very slight. According to Fig. 8, in the autumn at station 1, the measurements of temperature and salinity were conducted at a depth of5 mand18 m; both of the sea areas are located in the surface layer (mixed layer). Therefore, it can be concluded that almost homogeneous conditions existed in these areas, and as a result the surface and subsurface currents' velocities at this station are equal due to the existence of the barotropic current.

At the station 2, the measurements were conducted at a depth of 5 m and 47 m; one area was located in the surface layer and the other one located at the thermocline layers. Thus the currents' velocity difference at these two areas were a little more natural due to the density differences.

Considering the geometry of the seabed or substrate, and a sharp slope of the study area (Fig. 8 and 9) that created a pressure gradient, and the rate of the currents at these three stations were more than what was expected of the currents' wind driving force, we can conclude that a part of the strong coastal currents are caused by the costal bathymetry shape and its severe slope.

3.3 Low Frequency Motion

The spectral analysis results for the u and v components of the three stations are shown in Fig. 10. It shows that on the west coast of the southern section of the Caspian Sea, the low-frequency motions have considerable energy such that cyclonic and anticyclonic motions have been observed in a 10-day period. Also, there was a peak of energy from the anticyclonic motion for a period of 2.5 days in the area. The spectral analysis charts comparison of the three stations show an energy increase that can be observed from station 1 toward station 3. The existence of motions such as Kelvin waves and similar to it in this area has been reinforced because the direction of the coastal currents was from the west to the east (cyclonic) and the spectral analysis has indicated an energy peak for motions with a period of a few days. These motions in the low frequency that have considerable energy were observed along the whole coast of the Caspian and also in the continental shelf off Feridoonkenar Bay[19].

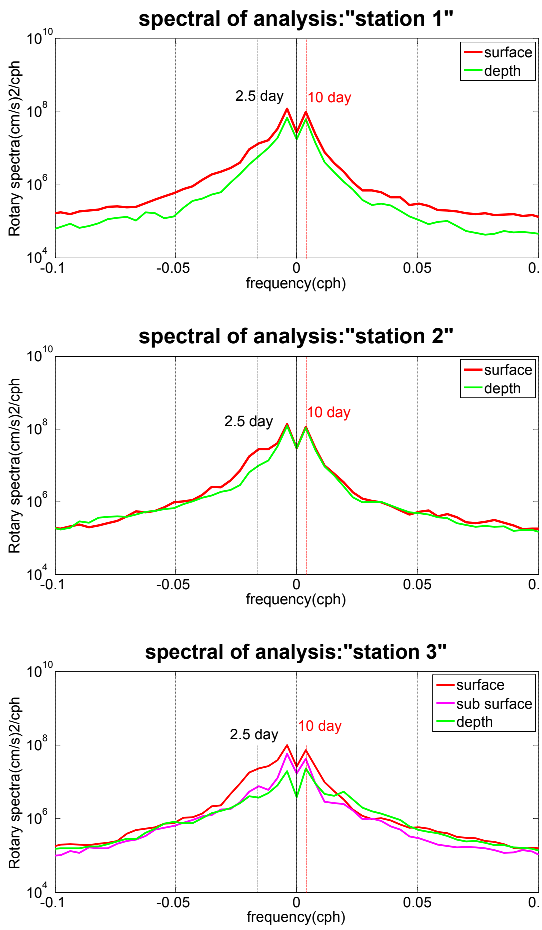

Figure 10. Top: Rotary spectrum of hourly currents for station 1 (depth: 20 m). Middle: Rotary spectrum of hourly currents for station 2 (depth: 50 m). Bottom: Rotary spectrum of hourly currents for station 3 (depth: 200 m)

4. Conclusion

Based on the researches conducted by Kynsh et al. [20], Ibrayev et al[21] and Shiea et al[22], one of the main factors of the general circulation model of the Caspian Sea is the wind force and then thermohaline circulation. But due to coastal currents in the area (the western part of the southern Caspian Sea area), and the fact that the currents' velocity of the shoreline has much more impact than the effect of winds on current wind driven force and that the currents from the surface to the substrate or seabed, in most cases is bathymetric, we can conclude that other important factors besides the density gradient and wind stress impact coastal currents. Among the sea factors we can mention the severe costal slope that can cause a pressure gradient and the formation of the currents in the area.

Also, one can hypothesize the existence of motions such as Kelvin waves in the area because of the presence of low-frequency oscillations with high energy that shows motions between 2 to 10 day periods in this area, and the direction of the prevailing currents in these stations, which have been from the west to the east.

Acknowledgment: We would like to thank the Department of Physical Oceanography of the Iranian National Institute for Oceanography and Atmospheric Science (INIO) for providing current and temperature data.

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  DOI: https://doi.org/10.30564/jmsr.v1i1.550