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Seasonal changes of stability and double diffusive processes in the pit of the Strait of Hormuz

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Abstract

Oceanic pits are often unknown due to their enclosed nature and lack of exchange with the surrounding environment, and they are often overlooked and neglected by researchers. The study area of the current research is a pit located in the Strait of Hormuz, near the south of Greater Tunb Island, which has not been previously studied. Its depth is more than 185 meters, with longitude coordinates of 55.321 degrees East and latitude of 26.122 degrees North. However, the depth of these coordinates has been recorded as 68 meters on GEBCO's international website. The seasonal data used are temperature and salinity obtained from one seasonal field measurement of the Persian Gulf Explorer in 2018 which were measured using a CTD (Conductivity, Temperature, and Depth) instrument with a time step of one second. Then the related graphs of temperature, salinity and potential density were plotted and analyzed in Ocean Data View (ODV) software package. Moreover, the Brunt-Väisälä buoyancy frequency and Turner's angle were calculated and plotted using ODV. The average values of each component were calculated by the weighted averaging method in ODV. The results showed that the pit is generally stable. The surface layer of winter had a higher density than the other seasons, but the summer unexpectedly had a higher density than the other seasons in the deep trapped water of the pit. The results also showed that all three states of stability, instability and double diffusion convection occur in all seasons in the pit. The layers which mostly consist of double diffusion convection were observed in the following order: summer, winter, spring and autumn, respectively. The salt finger regime in warm seasons (spring and summer) and the diffusive convection regime in cold seasons (autumn and winter) had a greater contribution to creating double diffusion convection. The strong diffusive regime in warm and cold season seasons was9% and 4%, respectively, and the weak diffusive regime in warm and cold season seasons was 5% and 22%, respectively. Meanwhile, the strong salt finger regime in warm and cold seasons was 18% and 8%, respectively and the weak salt finger regime in warm and cold seasons was 21% and 9%, respectively. The relationship between temperature and stability clearly showed that there was no seasonal thermocline layer in autumn and winter. In summer, the thermocline layer is stable and the surface mixed layer was highly unstable. Surprisingly, both the most stable and unstable layers were located in deep waters of spring. In general, autumn was the most stable season and spring was the most unstable season according to the measured data of the Persian Gulf Explorer (2018) in the pit of Strait of Hormuz, near the south of Greater Tunb.

Keywords: Brunt-vaisala frequency, diffusive convection, double diffusion, ODV, salt fingering, turner angle

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1 Introduction

The world's oceans are vast habitats for countless creatures that settle, spawn, dig, or feed on the seafloor. They also influence the shape of the ocean floor. How exactly this takes place has been scarcely investigated so far. In an interdisciplinary study, geoscientists, biologists, and oceanographers, have examined crater-like depressions hereafter referred to as pits (Kiel University, 2023) on the seafloor (e.g. the North Sea). Pits are different from trenches. Oceanic trenches are prominent, long, narrow topographic depressions of the ocean floor (Rowley, 2002), while pits are crater-like depressions and poorly understood because they are not usually depicted on general maps.

On the other hand, density plays a key role in the stratification of the ocean water column especially pits as a unique enclosed water column. Factors affecting the density of ocean water include temperature, salinity, and pressure. The effect of pressure can only be seen in deep water due to the compressibility of the water column. Therefore, in investigations below the depth of 1000 meters, the compressibility effects of the water column are usually ignored. The stratifications of the water column in waters with a depth of less than 1000 meters are under the influence of two important components of temperature and salinity with different molecular diffusion coefficients ($K_T=1.4\times10^{-7}$ m^{2}s^{-1}, $K_s = 1.4\times10^{-9}$ m^{2}s^{-1}) (Stewart, 2008). When a light package of water is placed on top of a heavy water package, the water column is statically stable and hence there is no tendency to move vertically in the water column. But if the heavy flow is placed on top of the light flow, the heavy one sinks and the light one rises, and the water column has an unstable density distribution. Stability is a measure of the amount of work required to move a particle up or down in the water column. In other words, stability can be compared to the movement of the water column up and down in the form of an oscillation (Jamshidi, 2015), whose buoyancy frequency is the Brunt-Väisälä buoyancy frequency, N, according to equation 1 (Stewart, 2008; Kaempf, 2010).

$$N(z) = -\frac{g}{\rho_0}\frac{\partial \bar{\rho}}{\partial z} = Eg \qquad (1)$$

If the buoyancy frequency is positive (Table 1), the fluid parcel oscillates around its initial depth, which physically means that when the parcel is displaced upwards, it will be heavier than its new height and will feel a downward restoring force. While returning to its initial height, the package gains vertical speed and when it reaches the initial level, due to its speed, it will move lower than its initial height. In the new environment, it will be surrounded by a heavier fluid and will move upwards with a positive buoyancy force, and the oscillation cycle will be repeated. If the buoyancy frequency is negative (Table 1), then the displacement of the fluid package increases exponentially and static instability occurs. If the buoyancy frequency is zero (Table 1), the fluid package will be in a neutral state, that is, when moving, there is no difference in that new location, because no buoyancy force is created (Aliakbari Bidokhti, 2018). The frequency of buoyancy is the highest in the thermocline and the lowest in the deep areas and mixed layer (Pedlosky, 2003). If instability occurs in a fluid with density stratification, the main reason for instability is the difference in the faster diffusion coefficients of the temperature component compared to the salinity component, which is 100 times larger than salinity. This is because thin layers can lose their heat while moving but keep their salinity. As a result, the stratified structures created in the vertical profiles of salinities can be maintained for a longer period concerning the vertical profiles of temperatures. Therefore, it is expected that the vertical structures of layers are more specific in the salinity diagrams (Alyasin et al., 2013). This feature causes strong movements and mixing in the vertical direction, which is called double diffusion with the abbreviation DD (Ruddick and Kerr, 2003). Figure 1 shows the possible states of the water column. Figure 1(a) shows the stable state and Figure 1(b) shows the unstable state. The two other cases (Figure 1(c) and (d)) show double diffusion convection, which occurs when the distribution of salinity and temperature of the water column have opposite effects on the density distribution of the water column.

Table 1. Brunt-Väisälä buoyancy frequency and Tu angle ranges (Gill, 1982; Ruddick, 1983, Robertson et al., 1995; Stewart, 2008; Kaempf, 2010).

Buoyancy frequency	Stability State	Turner's angle ranges (degree)			Description
N<0	Statically unstable	Tu<-90 and Tu>90			-
N=0	Neutral stability	Tu=-90 or -90			-
N>0	Statically stable	45<Tu<90	45 < Tu ≤ 67.5	Weak SF	Double diffusion (DD): the salt finger (SF) regime, the most intense state when TU is close to 90 degrees, the salinity gradient is an unstable factor.
			67.5 ≤Tu < 90	Strong SF	
		-45<Tu<45	The water column is doubly stable (DS). Temperature and salinity are stabilizing factors and diffusion convection (DC) does not occur.		
		-90<Tu<-45	-67.5≤Tu <- 45	weak DC	Double diffusion (DD): the diffusive convection (DC) regime, the most intense state when TU is close to -90 degrees, the temperature gradient is an unstable factor.

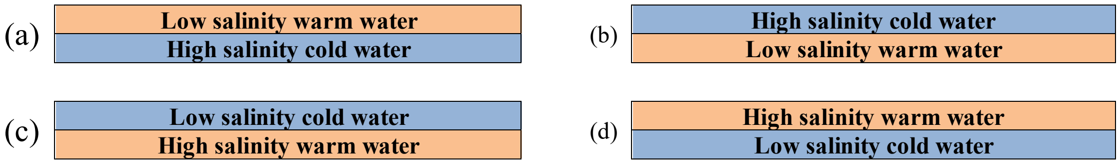

Figure 1. Possible combinations of temperature and salinity of the water column. (a) static stability, (b) static instability, (c) double diffusion convection (DD) of the type of the Diffusive Convection regime (DC), (d) double diffusion convection of the type of salt finger regime (SF).

There are two different types of Salt Fingering with the abbreviation SF and Diffusive Convection with the abbreviation DC in double diffusion convection (Bidokhti Ali Akbari and Sabbagh Kashani, 2003). The physical concept of the double diffusion convection process is the release of part of the potential energy by an unstable vertical gradient of temperature or salinity (Kantha and Clayson, 2000). The quantification of double diffusion convection is done based on the definition of Ruddick (1983), the Turner angle according to equation (2), which is used when studying the stratification of seas and oceans and double diffusion convection. Equations (3) and (4) show the salinity compression coefficient and the temperature expansion coefficient used in equation (2), respectively.

$$\tan^{-1}\left(\frac{\alpha\Delta T-\beta\Delta S}{\alpha\Delta T+\beta\Delta S}\right)=\tan^{-1}\left(\frac{R_\rho-1}{R_\rho+1}\right) \tag{2}$$

$$\beta=\frac{1}{\rho}\left(\frac{\partial\rho}{\partial S}\right)_{T,P} \tag{3}$$

$$\alpha=\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_{S,P} \tag{4}$$

Equation (2) can describe the vertical stability and show how the density of the water column changes with depth by considering that the density is related to the temperature and salinity. Equation (2) can also determine the type of double diffusion convection (Table 1). Double diffusion plays an effective role in spreading temperature and salinity in the sea, and its effects cause the formation of some layers in the sea, which may affect the vertical diffusion coefficients of temperature, mass and momentum. The process of double diffusion occurs in different conditions and forms and creates instability and mixing (Stern, 1960). Double diffusion mixes the ocean water. Merryfield et al., (1999) using a numerical model of the ocean circulation that included double diffusion, found that double diffusion mixing, although it has little effect on large-scale ocean circulations, but it is effective in the local distribution of temperature and salinity. There are studies related to the stability and double diffusion convection in the Strait of Hormuz, such as Mohammad Pour et al., (2023), Solgi et al. (2022, 2023), Azizpour et al. (2017), Ansari et al., (2010) are among them. There are very few studies about the pit of the Strait of Hormuz. In only one study, Koochaknejad and Hamzei (2022) studied the distribution of the winter bloom of *Noctiluca scintillans* in the Strait of Hormuz, and one of their stations was on the position of this pit coordinates. In that study, the temperature, salinity, and chlorophyll-a were investigated only up to a depth of 100 meters only during the winter season. In other studies, the existence of this pit of the Strait of Hormuz region has not been mentioned. The present study was conducted to seasonally investigate the stability and convection of double diffusion in the pit of the Strait of Hormuz, located in the south of Greater Tunb Island, which is the first of its kind to be proposed in the Persian Gulf region.

2 Methods

2.1 Study area

The Strait of Hormuz (26 degrees 30 minutes north and 56 degrees 30 minutes east) is a waterway that connects the Persian Gulf to the Gulf of Oman and is important in terms of research, economy, military and politics (Reynolds, 1993). The Islamic Republic of Iran is located in the northern part of the Strait of Hormuz, and Oman and the United Arab Emirates are located in the southern part. The average width of the Strait of Hormuz is approximately 56 km (Reynolds, 1993). The maximum depth of the Strait of Hormuz increases from west to east and north to south, except for its located pits. In general, oceanic pits are one of the unknown regions of the earth. Although the maximum depth of the Strait of Hormuz increases from west to east and north to south, and it is relatively well-known in terms of bathymetry, the pits of the region are poorly understood and until recently, there were no reports of the existence of these pits in research. However, local fishermen and captains were aware of their existence and had military use of them by the United States Navy. The pit in the Strait of Hormuz is located in the south of Greater Tunb Island, with a depth of more than 185 meters, with longitude coordinates of 55.321 degrees East and latitude 26.122 degrees North. However, the depth of these coordinates has been recorded at 68 meters on GEBCO's international website.

2.2. The used data

In this research, the field data was measured by the Iranian National Institute for Oceanography and Atmospheric Science with the Persian Gulf Explorer in 2018 were utilized. The Persian Gulf Explorer is a Research Vessel, IMO 9770402, built in 2017 and many studies have utilized its measurements e.g. Momtazi and Sepahvand (2021), Ghaemi et al., (2021 and 2022), Kabiri (2022), Abedi et al., (2023), Ershadifar et al., (2023). The location information of the measured station (Figure 1) in different seasons of 2018 is shown in

Table 2. This station was in the south of Greater Tunb Island, as the pit of the Strait of Hormuz, where the depth was measured at 187 meters. The tidal range varies in different stations (Soyuf Jahromi, 2023) and is insufficient to extract energy in many parts of the Persian Gulf (Soyuf Jahromi and Emami, 2021). According to the study of Hoseini and Soltanpour (2022), the tide reaches 30 cm in the area of the studied station. Due to the depth of the station, and the small the small tidal range, the tidal effect has been ignored. Sampling was conducted in all seasons to a depth of more than 176 meters. Physical properties including temperature and salinity of water from the surface to near the bed were measured using a CTD (Conductivity, Temperature, and Depth) instrument with a time step of one second. The device used in this exploration was the Ocean Seven 316 model made by Idronaut, Italy.

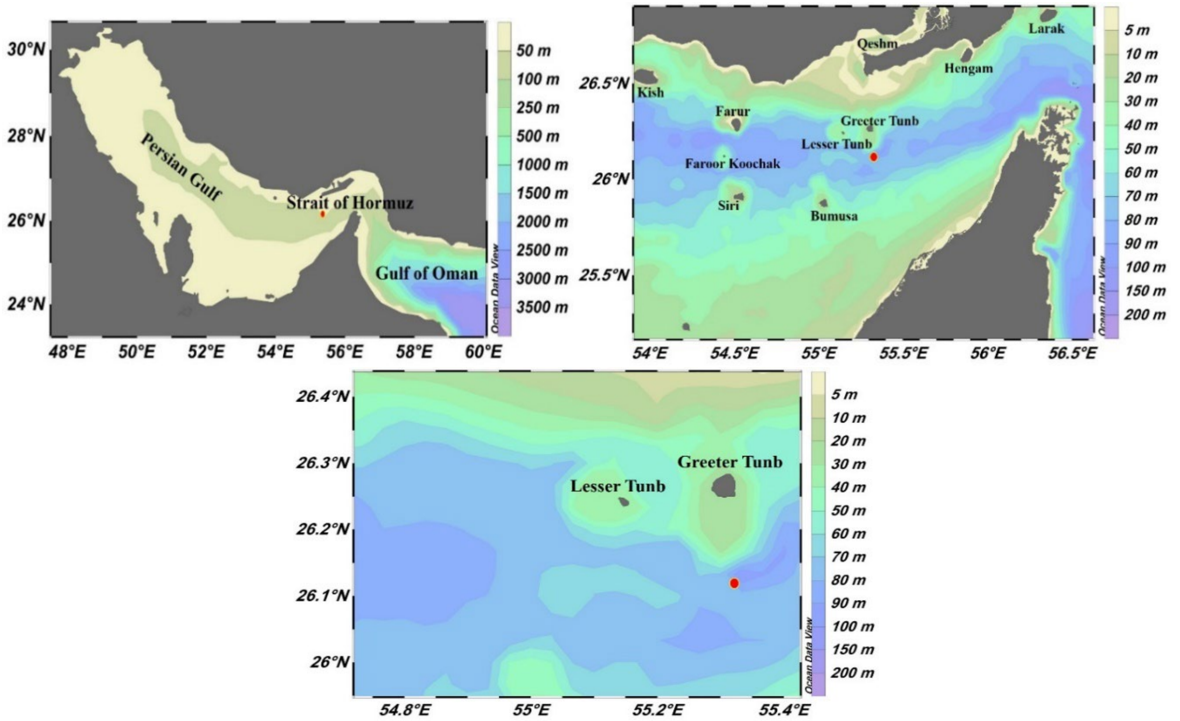

Figure 2. Locations of the Strait of Hormuz pit, near the south of Greater Tunb to the Strait of Hormuz and Persain Gulf, plotted by ODV.

Table 2. The last measured depth at the selected station of the pit of the Strait of Hormuz, located in the south of Greater Tunb Island.

Season	Location		Last measured depth (m)
	Longitude (°E)	Latitude (°N)	
Spring	55.321	26.122	176.78
Summer	55.321	26.122	179.61
Autumn	55.321	26.122	186.78
Winter	55.318	26.121	177.78

2.3 The data analysis

Ocean Data View software package was used to analyze the measured data. ODV is a computer software program related to the Alfred Wegener Institute (AWI) that is used to graphically display oceanographic and other geographic features and time series data. This software allows the user to store and analyze large data sets on small, portable hardware, and can expand and extend any existing data set as new data becomes available (Schlitzer, 2022). This software is used in various sciences such as physical oceanography (Mohammad Pour et al., 2023; Payandehi et al., 2023; Lashkari et al., 2023), meteorology (Aboobackr et al., 2020), chemical oceanography (Gourain et al., 2019), marine biology (Forsch et al., 2021), marine geology (Bao et al., 2019), marine environment, etc.

In this research, the data from the global ocean database, which was included in the default settings of ODV software, was used as the primary basis of the field measurement data. First, the data of the station, which were in text format, were checked in Excel and then imported to ODV. The temperature and salinity values were obtained directly from the field data, and the potential density values were calculated using the sea water state equation (TEOS-10), buoyancy frequency (equation 1) and Turner's angle (equation 2) in the software. Then the temperature, salinity and potential density were plotted as station charts and values of buoyancy frequency and Turner's angle were plotted as scatter charts according to depth. Also, the average values of each component were calculated by the weighted averaging method. In order to draw pie charts that show the frequency of Turner's angle values, first the calculated values of each cross section were extracted from the ODV software in the form of a spreadsheet file in text format. Turner's angle values were arranged in ascending order and then the percentages of static instability, weak and strong Diffusive Convection regime, doubly stable, weak and strong salt finger regime were calculated and plotted as pie charts for each season.

3 Measurement, observation and calculation

Figure 3 shows the graphs of temperature, salinity and potential density anomaly in four seasons of the year. The maximum temperature was in summer (31.44 degrees Celsius) and its minimum was in spring (21.74 degrees Celsius); the maximum salinity occurred in winter (41.11 psu), while its minimum was in spring (37.09 psu). In the summer, the potential density has both maximum (28.6 kg m^{-3}) and minimum (22.91 kg m^{-3}) values.

As shown in figure 3 (left), the temperature of the water column in spring and summer displays three mixed layers: mixed layer, thermocline mixed layer, and deep layer, but in autumn and winter, the water column is mixed and forms relatively one single layer. The graphs of salinity (Figure 3, middle) and potential density (Figure 3, right) show that in terms of these two physical properties, the water column has three layers in all seasons of 2018. The warmest waters are located in the surface layer in summer, spring, autumn and winter, respectively, and the warm trapped waters in depths below 75 meters occur in autumn, winter, summer and spring, respectively. The surface layer has less salinity than the layer with the depths more than 75 meters. The salinity of the surface layer decreases from autumn, winter, to summer and spring, respectively. In trapped waters with the depths greater than 150 meters, winter and summer have the highest salinity, and autumn and spring have less salinity in the depths. The potential density in the surface layer is higher in winter, autumn, spring and summer, respectively. In the depths greater than 75 meters, which are the trapped waters of the pit, the density in summer, spring and winter is more than the density in autumn (Table 3). In autumn and winter, the pattern of potential density is more closely related to salinity, and therefore, in these two seasons, the salinity of the pit has a greater contribution to the change of potential density.

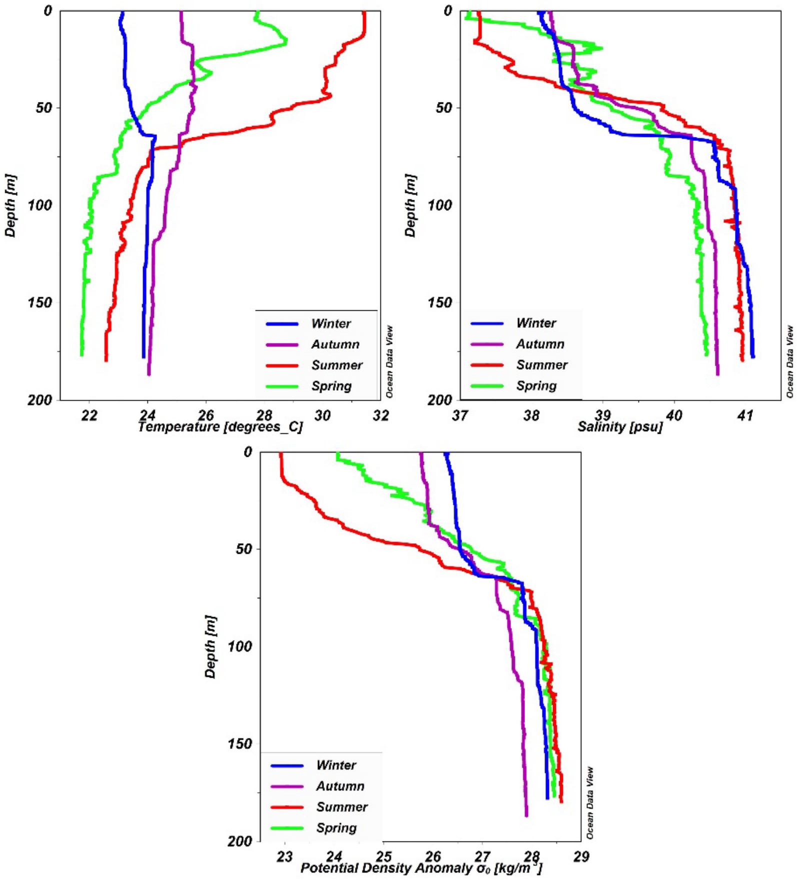

Figure 3. Seasonal variations of temperature (left), salinity (middle) and potential density (right) according to depth.

Figure 4 shows the seasonal changes of buoyancy frequency and Turner's angle according to depth. In spring, the least unstable layers are observed at a depth of 36-75 meters. The diffusive convection regime is seen sporadically at depths of (6, 9, 12, 13, 29, 30, 31, 74, 86, 97 and 124 meters) and the salt finger regime is observed from the surface up to 175 meters. In the summer, there are very few unstable layers in the first 100 meters. The most unstable layers are observed at depths more than 100 meters. The diffusive convection regime occurs at depths of 18 to 56 meters, and below that, layers consisting of the diffusive convection regime occasionally appear at depths of (69, 70, 98, 101, 113, 114, 121, 149 and 160 meters). The finger regime is observed at depths of 12 to 176 meters, although it is very scattered up to a depth of 67 meters.

Table 3. comparison of seasonal changes of temperature, salinity and density in the surface layer and the deep layer of the pit of the Strait of Hormuz, located in the south of the Greater Tunb Island, based on the measurement data of the Persian Gulf Explorer, 2018.

Variable	Layer	Seasons (left to right: Maximum to Minimum)			
Temperature	Surface mixed layer (Depth less than 20 m)	Summer	Spring	Autumn	Winter
	Deep layer (Depth more than 75 m)	Autumn	Winter	Summer	Spring
Salinity	Surface mixed layer (Depth less than 20 m)	Autumn	Winter	Summer	Spring
	Deep layer (Depth more than 75 m)	Winter	Summer	Autumn	Spring
Density	Surface mixed layer (Depth less than 20 m)	Winter	Autumn	Spring	Summer
	Deep layer (Depth more than 75 m)	Summer	Spring	Winter	Autumn

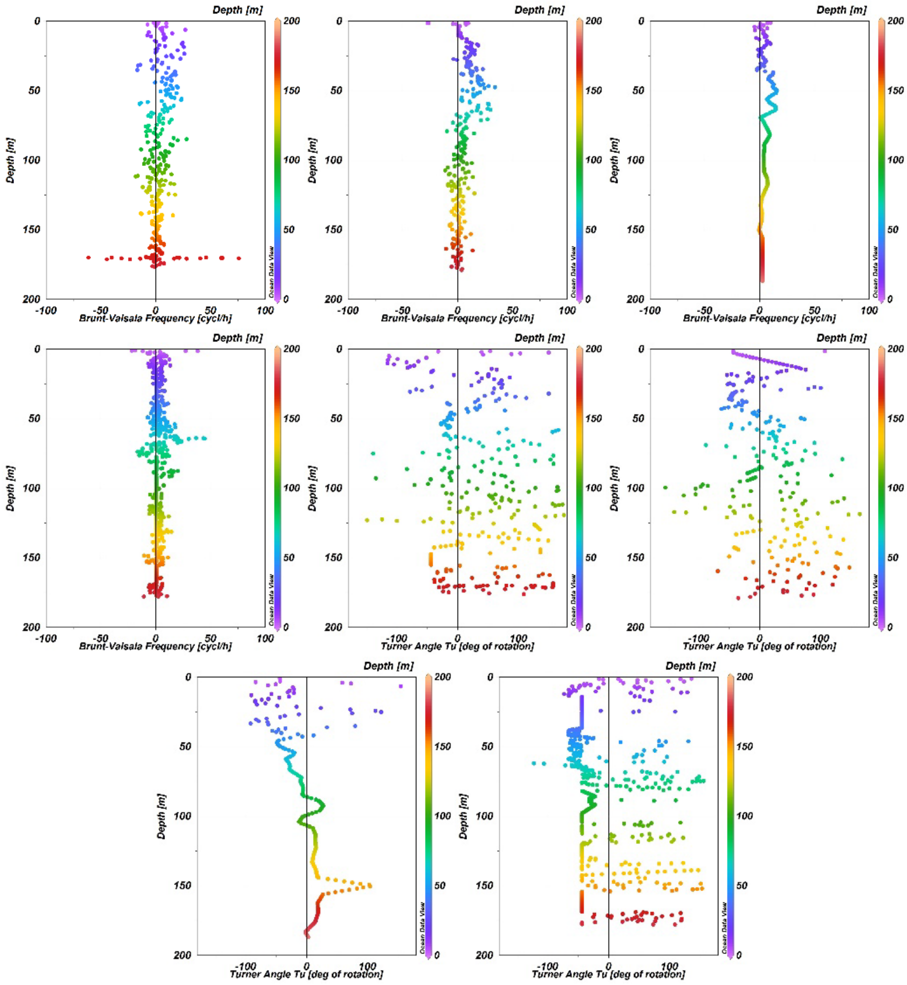

Figure 4. Seasonal changes of buoyancy frequency (top) and Turner's angle (bottom) according to depth. From left to right: spring, summer, autumn and winter.

In autumn, the most unstable layers are seen at depths of 4 to 35 meters, and instability is then observed only at depths of 148 to 151 meters. The salt finger regime is visible at at different depths (such as 4, 23, 26, 35, 146, 147, 148, 152, 153, 154 and 155 meters). The diffusive convection regime is observed only at depths of 3 to 49 meters. A comparison between the diffusive convection and the salt finger regimes in the autumn shows that from the surface to the depth of 49 meters, the role of the diffusive convection regime is more prominent than the salt finger regime.

In winter, diffusive convection regime is observed at depths of 6 to 13 meters and 37 to 65 meters, while the salt finger regime extends from the surface up to 178 meters. Table 4 shows that the more stable layers are formed in spring, winter, summer and autumn, respectively. And the most unstable layers are observed in spring, summer, winter and autumn.

Figure 5 shows the frequency of Turner's angle. In all seasons, double stability has the highest percentage of abundance in the water column, which is the maximum in autumn (79%) (indicated by the red color in Figure 5). The highest static instability is related to the spring (28%), which is more than twice the other seasons (Figure 5, indicated by the purple color).

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Table 4. Seasonal changes of maximum and minimum buoyancy frequency.

Season	Spring	Summer	Autumn	Winter
Maximum of buoyancy frequency (rpm)	75.61	33.95	15.58	44.57
The depth corresponding to the maximum of buoyancy frequency (meters)	169.9	47.4	49.82	64.29
Minimum of buoyancy frequency (rpm)	-61.45	-27.61	-4.75	-21.88
The depth corresponding to the minimum of buoyancy frequency (meters)	170.48	1.33	3.95	0.98

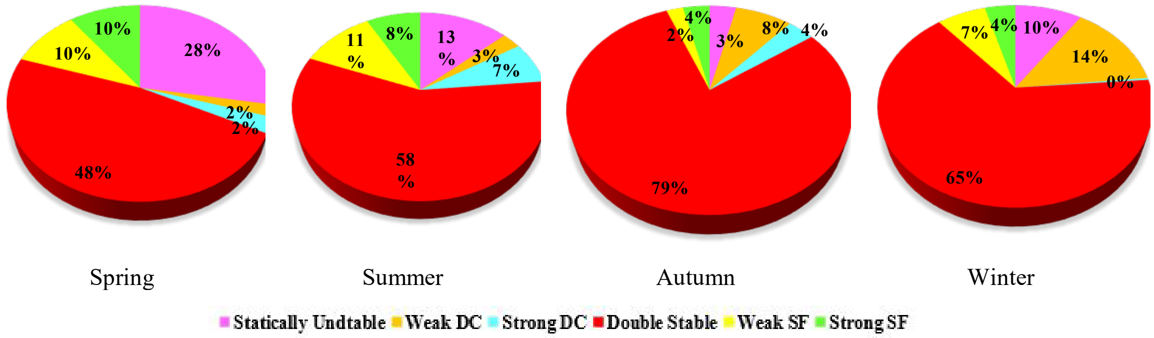

Figure 5. The frequency percentage of Turner's angle in different seasons of 2018.

Table 5. Seasonal changes in the frequency (in percentage) of stability, instability and double diffusion convection events in the pit of the Strait of Hormuz.

The type of phenomenon		Spring			Summer			Autumn			Winter		
		Strong	Weak	Total	Strong	Weak	Total	Strong	Weak	Total	Strong	Weak	Total
doubly stable		48			58			79			65		
The double diffusion convection	salt finger regime	10	10	20	8	11	19	4	2	6	4	7	11
	diffusive convection regime	2	2	4	7	3	10	4	8	12	0	14	14
	Dominant type	salt finger regime			salt finger regime			diffusive convection regime			diffusive convection regime		
	Total	24			29			18			25		
Static instability		28			13			3			10		

According to Table 5, the most layers consisting of double diffusion convection are observed in summer (29%), winter (25%), spring (24%), and autumn (18%), respectively. Based on table 5, in warm seasons (spring (20%) and summer (19%)) the salt finger regime plays a greater role in creating double diffusion convection, while in cold seasons (autumn (12%) and winter (14%)), the diffusive convection regime is more significant. In spring, the share of weak and strong salt finger regimes is equal, in summer, the share of weak salt finger regime is predominant, in autumn and winter, the share of weak diffusive convection regime is more than the strong one. In other words, the strong diffusion regime in the warm and cold seasons is9% and 4%, respectively, and the weak diffusion regime in the warm and cold seasons is5% and 22%, respectively. Conversely, the strong salt finger regime in warm and cold seasons is 18% and 8%, respectively, while the weak salt finger regime in warm and cold seasons is 21% and 9%, respectively. According to the information presented in Table 4, the most stable and unstable layers are observed in the deep trapped water of the pit in spring.

4 Discussion

Examination of the frequency of buoyancy (Table 3) shows that the most unstable layers are located in the surface waters of the pit in summer, autumn and winter, while in spring, they are found in the deep waters of the pit.. In autumn and winter, thermocline layers are not created inside the pit. The most stable layers occur in summer and in the thermocline layer, but in spring, the deep layer of the pit is more stable. According to Pedlosky (2003), the buoyancy frequency generally exhibits the highest values in the thermocline and the lowest in the deep waters and mixed layer. The data (Figure 3) clearly indicate that the thermocline was stronger in summer than other seasons, therefore, according to Pedlosky (2003), it can be expected that the frequency of buoyancy would be more in summer, but the occurrence of stable buoyancy in the deep waters of the pit in spring, may be related to salinity and seasonal changes and further investigation is required.

Investigating the double diffusion convection in the pit of the Strait of Hormuz showed that this area is favorable for creating both diffusive convection and salt finger regimes. The presence of both diffusive convection and salt finger regimes has been reported in the wintertime ROPME 2006 exploration (Mohammad Pour et al., 2023), the winter 2012 and spring and summer 2013 (Azizpour et al., 2017) in the Strait of Hormuz although they did not investigate the pit, their findings align with the present study.

Based on Table 5, it is evident that the water column inside the pit is doubly stable in all seasons, and the water column of the pit is more stable than unstable (autumn, 79%; winter, 65%; summer, 58%; and spring 48%, respectively). The rest of the water column has double diffusion convection and instability. In all seasons, double diffusion convection is observed more than instability in the water column of the pit, except for spring (Table 5). In warm seasons (spring and summer) the salt finger regime and in cold seasons (autumn and winter) the diffusive convection regime has a greater contribution in creating double diffusion convection. Additionally, Solgi et al. (2022, 2023) reported that with increasing in temperature and surface current in the Strait of Hormoz, the role of the salt finger regime becomes more prominent compared to the cold months in the Strait of Hormoz, which aligns well with the results of Table 4 of this current study of the pit. Therefore, it is confirmed that in the studied pit, the diffusive convection regime plays a more prominent role in cold seasons such as autumn and winter. Ansari et al., (2010) also stated that cold seasons are favorable for creating the diffusive convection regime and there are no necessary conditions for creating the diffusive convection regime in warm seasons. However, the results of Figures 4 and 5 of this study prove that both types of regimes are formed, but the dominant contributions of warm and cold seasons are different. In other words, in warm seasons (spring and summer) the salt finger regime and in cold seasons (autumn and winter) the diffusive convection regime is the dominant regime of double diffusion convection.

In other words, in warm seasons (spring and summer), the salt finger regime and in cold seasons (autumn and winter), the diffusive convection regime has a greater contribution to creating double diffusion convection. Moreover, the relationship between temperature and stability clearly shows that there is no seasonal thermocline layer in autumn and winter. In summer, the thermocline layer is stable, while the surface mixed layer was highly unstable. Surprisingly, both the most stable and unstable layers are located in deep waters of spring.

5 Conclusion

The present research aimed to study the seasonal stability and double diffusion convection in the pit of the Strait of Hormuz located in the south of Greater Tunb Island and showed that the water column of the pit in spring and summer exhibit three mixed, thermocline and deep layers. However, in autumn and winter it is relatively one single layer (mixed in terms of temperature). In terms of salinity and potential density, a three-layered structure (mixed, halocline/pycnocline and deep layers) can be seen in all seasons of the water column.

In the surface layer, the warmest waters are related to summer. While in deep trapped waters, the coldest waters are from autumn, not winter. In the surface layer, the salty water of the pit exists in autumn, whereas in deep trapped waters, the salty water of the pit exists in winter than other seasons. Additionally, the winter of the surface layer has a higher density than other seasons, but in deep trapped waters, summer shows the higher density than other seasons (Table 3).

The most stable and unstable layers in the depths of the trapped waters are observed in spring. The most (doubly) stable layers and the least unstable layers are related to autumn, and the most unstable layers and the least (doubly) stable layers are related to spring. In other words, in general, autumn was the most stable season and spring was the most unstable season according to the measured data of the Persian Gulf Explorer (2018). The highest diffusion convection is related to summer, while the least convection is related to autumn.

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