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Temporal and Spatial Variations of Sea Temperature in the Suez Gulf, Egypt

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ABSTRACT

Spatial and temporal variability in the water temperature in three surface, subsurface and near the bottom layers were investigated in the Suez Gulf. The gulf under study was divided into five lateral sectors, where temperatures were distributed horizontally and vertically to detect the spots of increase and decrease as well as what may have an impact on both. The pronounced seasonally fluctuations of water temperature were observed at the three layers. The water temperatures were recorde at their highest at the highest latitude (region E), resulting from the natural condition of mixing the gulf water with the worm Red Sea water and the highest intensity of solar radiation. Whereas, at the lowest latitudes (regions A and B), water temperature was at its lowest as a result of the natural condition of the land cooling and the huge human activity in the northern part of the gulf. A fluctuation was noticed in the water temperatures between 17.10 & 27.32^{o}C at the surface, 17.09 & 27.06^{o}C at the subsurface, and 17.00 & 26.86^{o}C near the bottom. Based on the vertical distribution of water temperature, a rising water temperature was recorded in the east of the sectors, while decreasing westward.

INTRODUCTION

The Gulf of Suez is the western arm of the Northern Red Sea. It is located between the Sinai Peninsula and the African continent; it lies between longitude 32° 28\ and 32° 34\E and latitude 29° 54\ & 29° 75\ N. After opening the Suez Canal, its strategic value increased. The shallow and narrow Gulf of Suez has a relatively flat bottom, with a depth ranging between 55 and 73m. The average length along the major axis is 13.2km; its average width is 8.8 km **(Hamed *et al.*, 2010)**. The Gulf of Suez is semi enclosed, long, shallow basin, with a relatively little exchange with both the Suez Canal and Red Sea. This gulf is located in a dry desert area, with scarce rainfall and high solar intensity, especially in the South. In the northern part of the gulf, there is a degree of minor contamination, which is aligned simultaneously with an increase in human activities (**Mahmoud *et al.*, 2020**)

The Gulf of Suez is located in an arid area **(Al-Horani *et al*., 2006)**, with an extermely low level of rainfall of about 1cm/day. The air temperature rises to 42.00^{o}C in summer and drops to 17.8 ^{o}C in winter (in Sharm El-Sheikh) **(Georgei & Bombeck, 2012)**. The Red Sea wind system is affected by the high coastal mountain ranges along the eastern and western coasts **(Sofianos, 2003; Sofianos & Johns, 2007)**. The wind direction over the northern Red Sea blows toward the Southeast, parallel to the Red Sea axis. The Gulf of Suez experiences three main winds, viz. the northwest (36.7%), the north (29.1%) and the west (7.4%), with mean wind speeds of 8-12ms^{-1}, **(Mortensen & Said, 1996; Abdallah, 2007; Papadopoulos *et al*., 2013; Abualnaja *et al*., 2015)**.

The spread of oil fields within the Gulf, the rising vapors of factories and mining on both sides of the gulf **(Hamed & Emara, 2006; Farhoud, 2009)**, as well as the spread of tourist resorts **(Mohamed *et al.*, 2007)** and the daily passing by of hundreds of cargo vessels, crossing the Suez Canal, and all of which can affect the quality of water in the Gulf of Suez.

The dominant tide in the Suez Gulf is semidiurnal, with an extreme value at the north side of the gulf (about 1.5m), decreasing to a lower value at El-Tor (nodal point), then decreasing (rising) again southerly **(Grace, 1931; Defant, 1961; Rady *et al*., 1994*a*)**. The Suez Gulf circulations flow against the prevailing wind in winter when the prevailing northwesterly winds are weak **(Morcos, 1970; Patzert, 1972; Murray *et al*., 1982)**. During the rest of the year, the southeastern currents are dominant, which are affected by the prevailing winds **(Murray & Babcock, 1982)**. However, recent findings call into question the foregoing, as it has been found that the dynamics of the Gulf of Suez are governed by the interaction of wind and density that force them **(Rady *et al*., 1998)**.

The surface water temperature in Suez Gulf decreases rapidly in the northward direction and westerly during winter **(Morcos, 1970; Said, 1998)**. In addition, the gulf experiences a significant temperature volatility, especially in winter. The maximum water temperature was recorded in the intertidal zone along the western coast of the Suez Gulf **(El-Komi *et al*., 2002)**. **El-Sabh and Beltagy (1983)** reported a narrow range change in the surface temperatures during the summer. The surface water temperature is high during July-September and low in January– March, with a difference in water temperature between the highest and lowest degrees at about 10^{o}C **(Fahmy *et al.*, 2005)**.

The aim of this study was to determine the temporal and spatial variations of the sea temperature and the factors impacting these differences with repect to the surface, subsurface and near the bottom of the Suez Gulf.

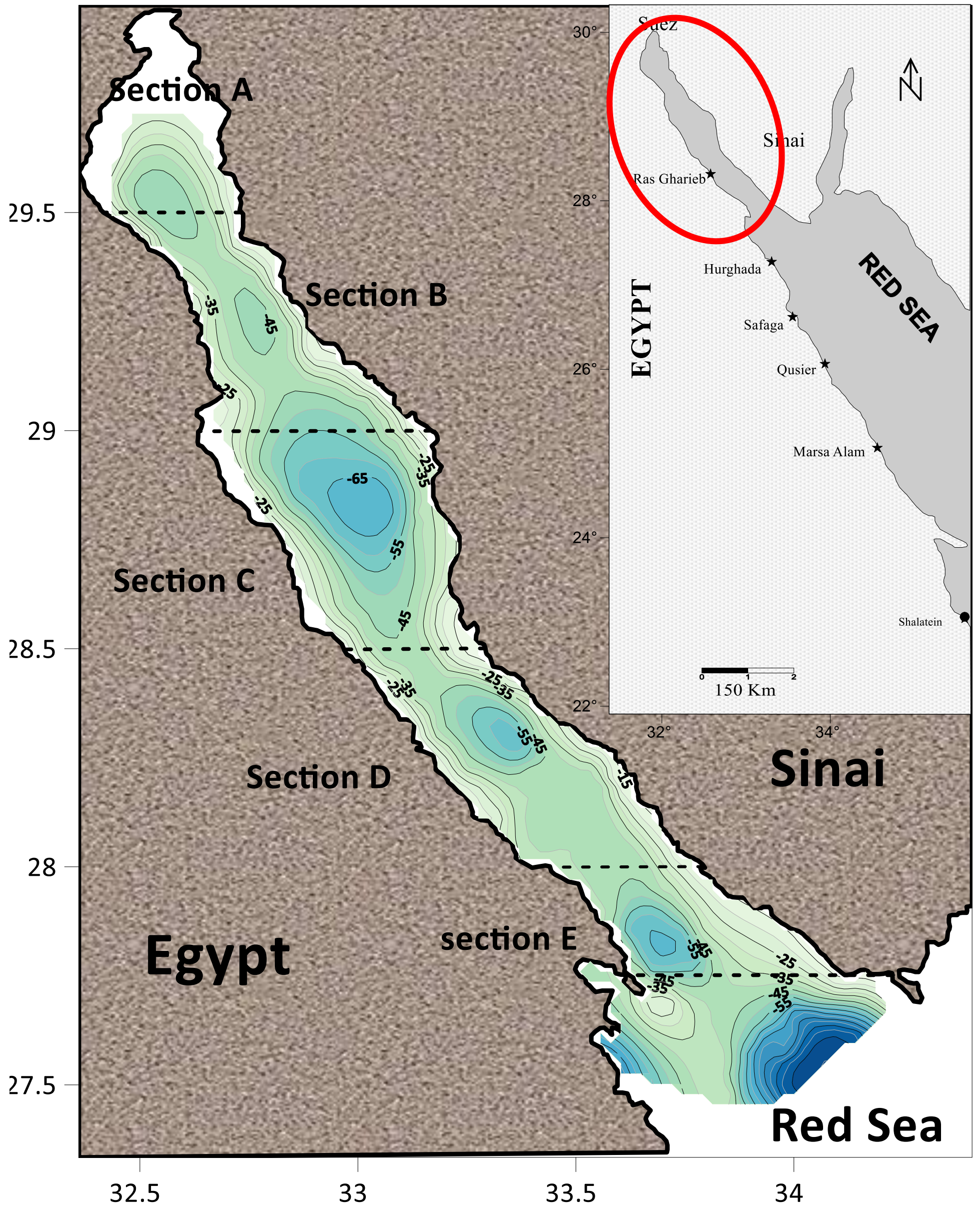

Fig. 1. Location and depths map of the Gulf of Suez

MATERIALS AND METHODS

The hydrographic data used were collected from the World Ocean Atlas 2015 (WOA15) and U.S. National Oceanographic Data Center (NODC). The Gulf of Suez was divided into five cross sectors; each sector has a half degree latitude, (Fig., 1 & Table 1). Thus, to study the change in temperature in time, the data were disaggregated by these sectors. To address the spatial temperature change, the data were separated into three levels, including the surface, subsurface and near bottom. Data were processed using a Microsoft Excel Worksheet as well as mapping with Golden Software\Surfer 12.

Table 1. Determinants of the five sectors

Sector	From latitude	To latitude
A	29°57'N	29°30' N
B	29°30' N	29°00' N
C	29°00' N	28°30' N
D	28°30'"N	28°00' N
E	28°00' N	27°42' N

RESULTS AND DISCUSSION

1. Temporal variations of temperature patterns

Fig. (2) displays the monthly mean water temperature of the Gulf of Suez in all the 3 layers, respectively. The highest water temperatures were recorded in region E (southern area), whether in the surface, subsurface or bottom layers, averaging 27.32^{o}C (August), 27.33^{o}C (November) and 26.86 ^{o}C (August) (Table. 1 & Fig. 2). Region E is characterized with a narrow range in temperature between the three layers since this area is opened to the Red Sea in addition to the existence of strong water circulations and northerly current between the southern gulf and te northern Red Sea, resulting in a water homogeneity **(Morcos, 1970; Patzert, 1972; Murray *et al*., 1982; Rady *et al*., 1998)**. Temperatures in region D follow the same behavior of region E in respect with temperature changes affected with temperature difference, whereas temperatures in region D are lower than those recorded in region E in the three layers of shape. In another way, The northern region registered the lowest temperature values considering the three layers; 17.10^{o}C was the value detected for the surface and subsurface layers, while a value of 17.94^{o}C was recorded in April near the bottom layer. Remarkably, the solar radiation is higher in the southern region than in the northern one **(Esbensen & Kushnir, 1981)**.

2. Spatial variations of temperature

Figs. (3,4, 5) elucidate the seasonally temperature in the Suez Gulf. It shows a seasonal cycle in which a continuous trend of seasonal warming occurs from winter to summer. Spatially, it always follows Zone A < Zone B < Zone C < Zone D < Zone E every year. This was partly attributed to a number of reasons, among which is the decline in solar energy radiation associated with the increase of latitude **(Simonot & Treut, 1987)**. Regions D & E being affected by the warm Red Sea water circulation **(Rady *et al*., 1998)** can stand behind the phenomenon under estimation. While, region A, B, C are affected by their geographical position being close to the northern coasts. In region B, there are two lenses with high temperature in winter and low temperature in summer. This region may be impacted by human activities.

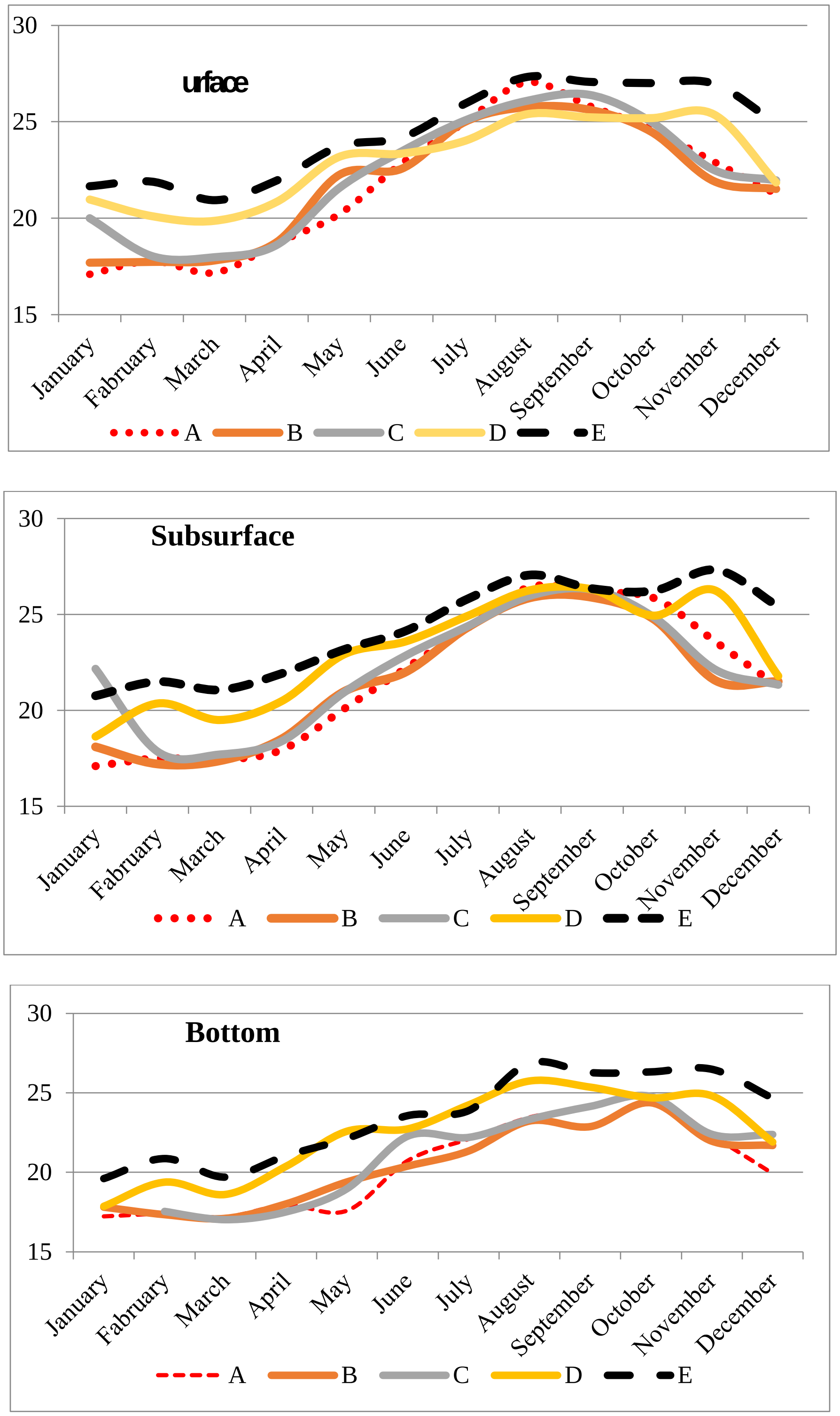

Fig. 2. The monthly variations of temperature in Gulf of Suez at the surface, subsurface and near the bottom for five sectors

The western lens is affected by the port of Manganese in Abu Zenima and the eastern lens is influenced by the tourist's activity in Ainsokhna and its resorts. There are obvious differences in the temperature values between region A and region E in winter, spring and autumn; these differences are 4.1°C, 2.7°C and 3.4°C, respectively. In contrast, the difference is absolutely slight in summer between region A and E reaching a value of 0.8°C, owing to the current at the opposite direction during the months of summer **(Rady *et al.*, 1998)**. The spatial distributions of the seasonal temperature are shown in Fig. (3). During winter, the surface temperature ranged between 17.1 and 21.9°C, with a mean surface temperature of 19.1°C. During spring, the surface temperature in most areas ranged between 18.6 and 24.2°C, with a mean of 21.8°C. While in summer, the surface temperature ranged between 24.0 and 27.3°C, with a mean of 25.8°C. On the other hand, the surface temperature during autumn fluctuated between 21.2 & 27.0°C, with a mean of 23.8°C.

In general, the temperature values in the subsurface layer are lower than those recorded in the surface layer, showing slight differences (Fig.4). The average of subsurface sea temperature during the four seasons recorded a slight decrease with the average values of 18.9°C, 21.3°C, 24.3°C and 23.9°C. Two factors have led to the lower water temperatures in the southern region (A) and the rise in the northern part, among which is the shallow water in the north and the slowing sea currents in this area; sector C is characterized by average temperatures in the three layers among the sectors but is closer to those in the northern layers.

Distributions of horizontal temperatures in the middle layer differ from those in the surface layer, which are affected by the atmosphere and human activities. Temperatures for the subsurface layer in winter appear low. The Gulf of Suez appears to be divided into two parts. The northern part has a temperature lower than 18^{o}C, and the southern affected Red Sea water temperature has a greater temperature than 18^{o}C, while temperatures rise in spring in the west side from the east as shown in Fig. (4). Temperatures for this layer are higher, influenced by the surface layer in most of the gulf, and in autumn temperatures vary in the lower layer. For the near bottom, the water temperature tends to decrease in two preceding layers, and its values were confined during winter between 17.02 & 20.86^{o}C, 17.51 & 23.57^{o}C during spring, 21.34 & 26.86^{o}C during summer in addition to 17.28 & 24.74^{o}C during autumn, as shown in Table (2). Temperatures near the bottom are cold in the northern half of the gulf under study (Fig. 5), while its worm in the southern half of the Gulf as a result of the circulation of the Red Sea throughout the year.

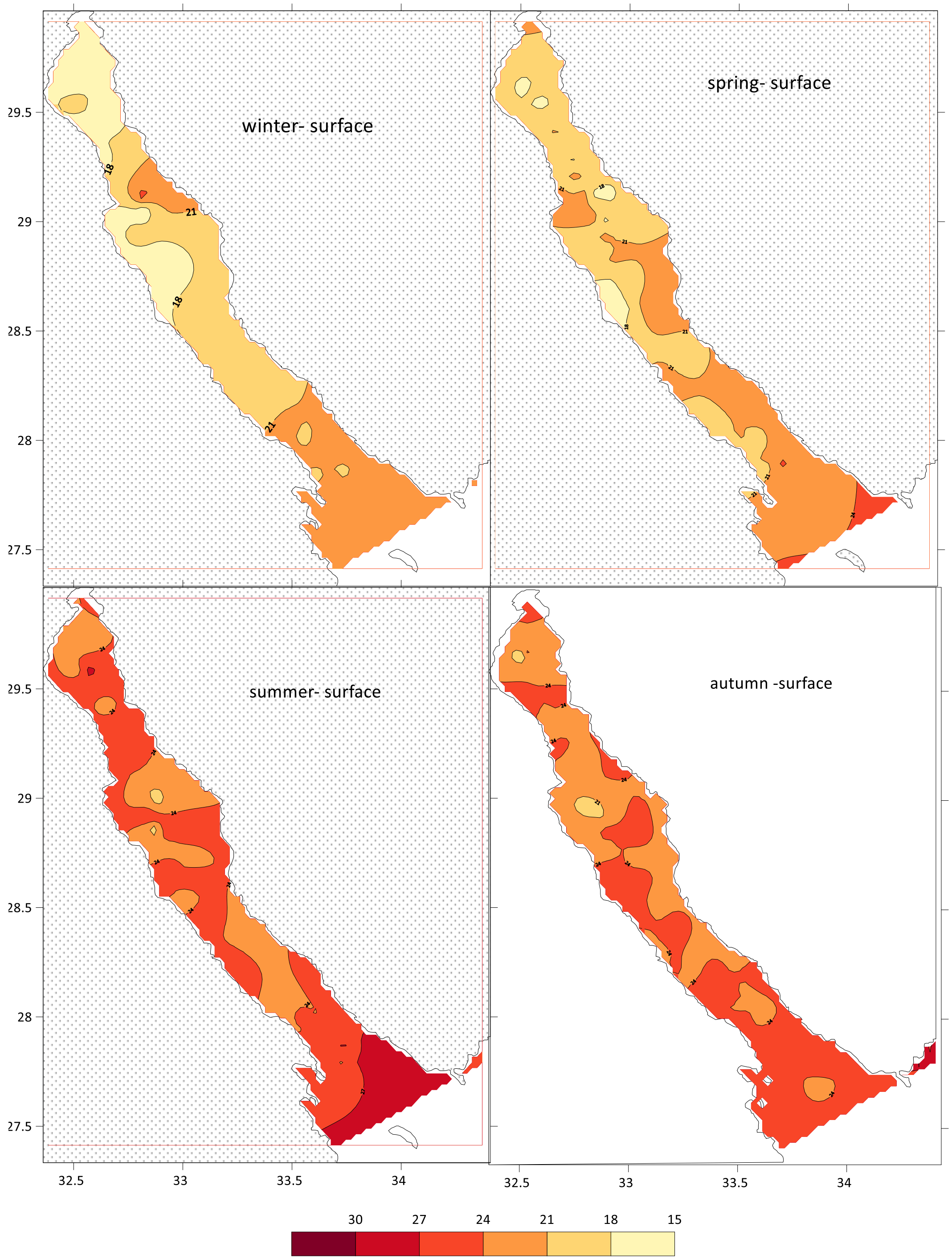

Fig. 3. The horizontal distribution of sea surface temperature during winter, spring , summer and autumn

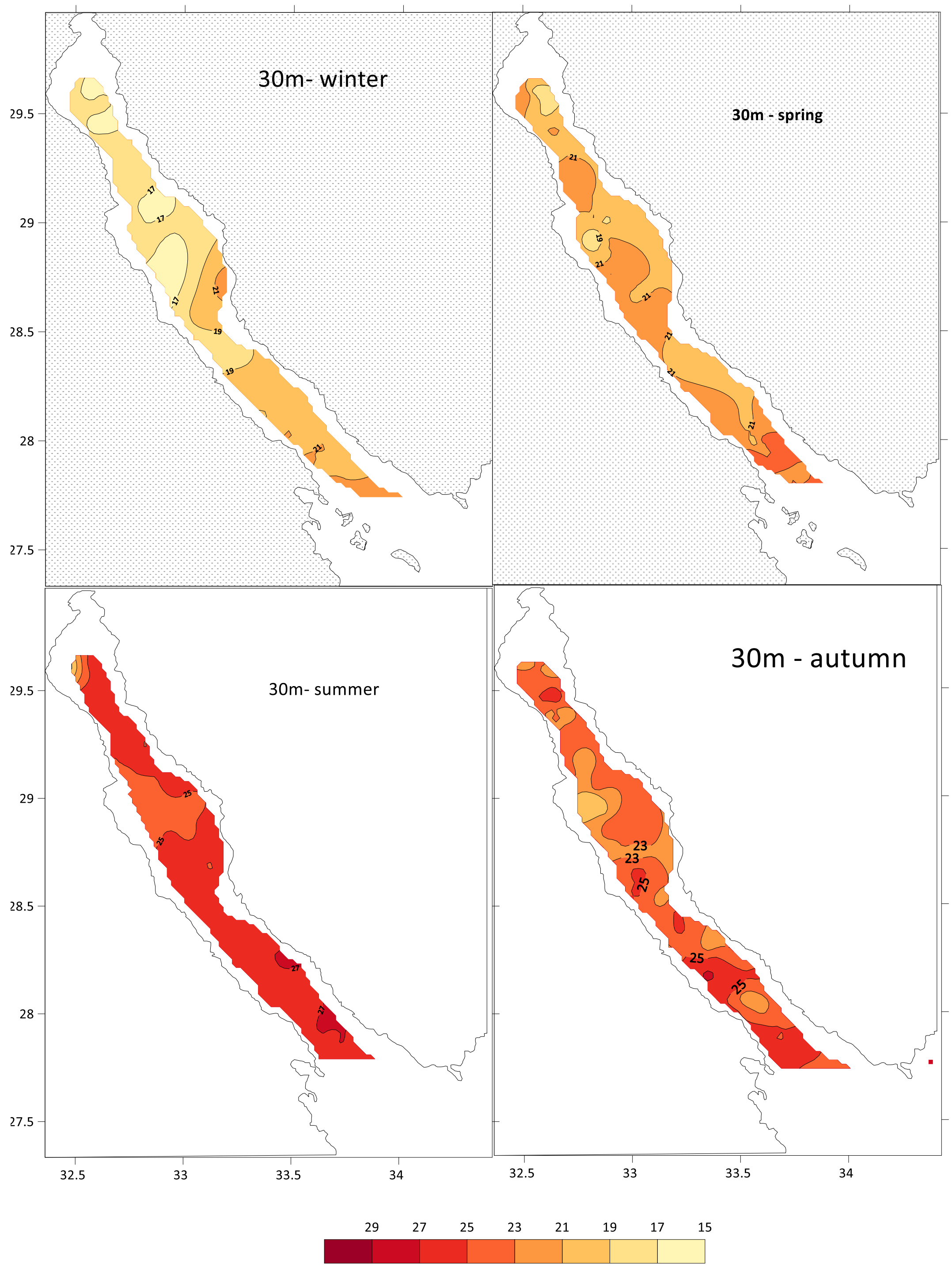

Fig. 4. The horizontal distribution of sea subsurface temperature during winter, spring , summer and autumn

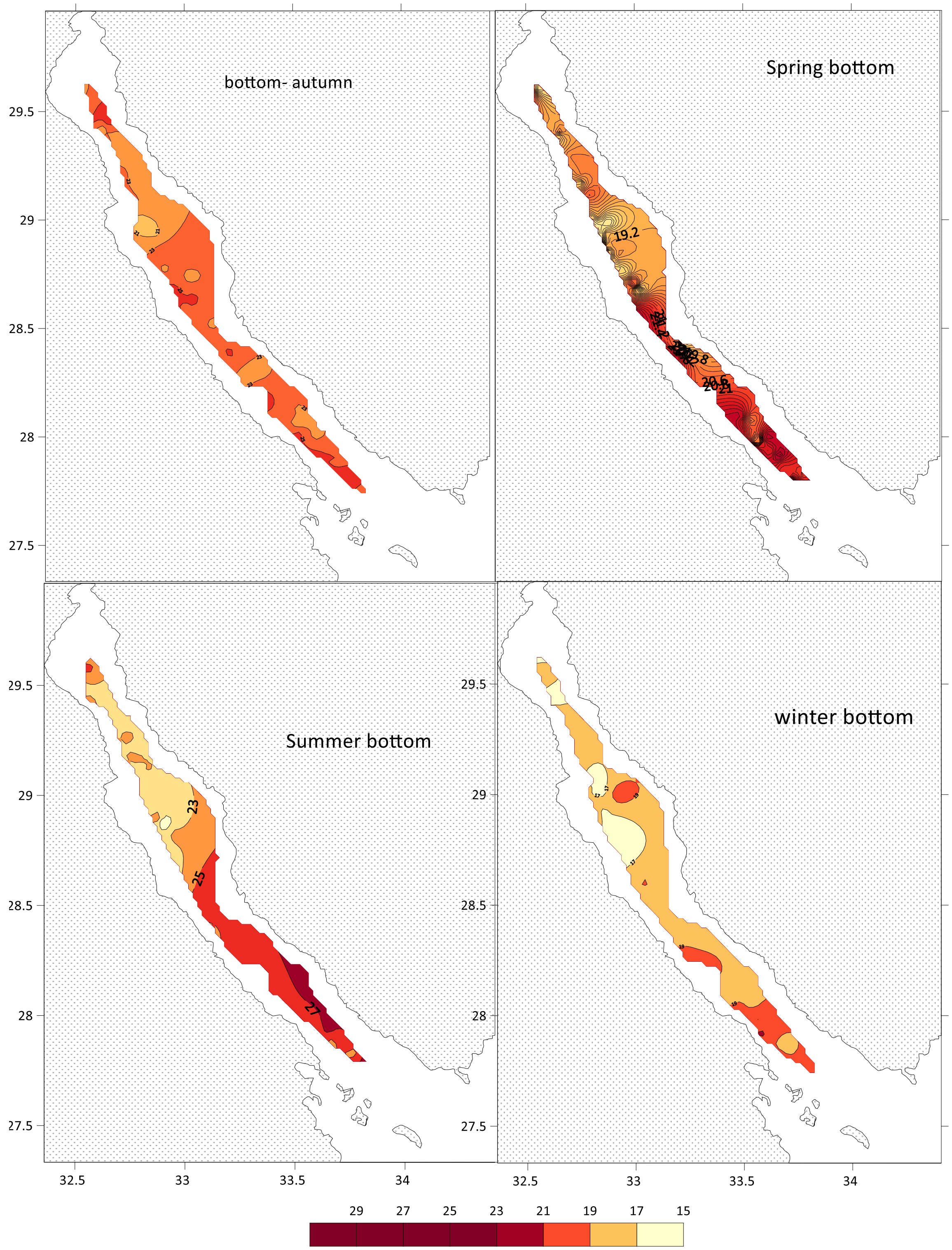

Fig. 5. The horizontal distribution of sea water temperature near the bottom during winter, spring, summer and autumn

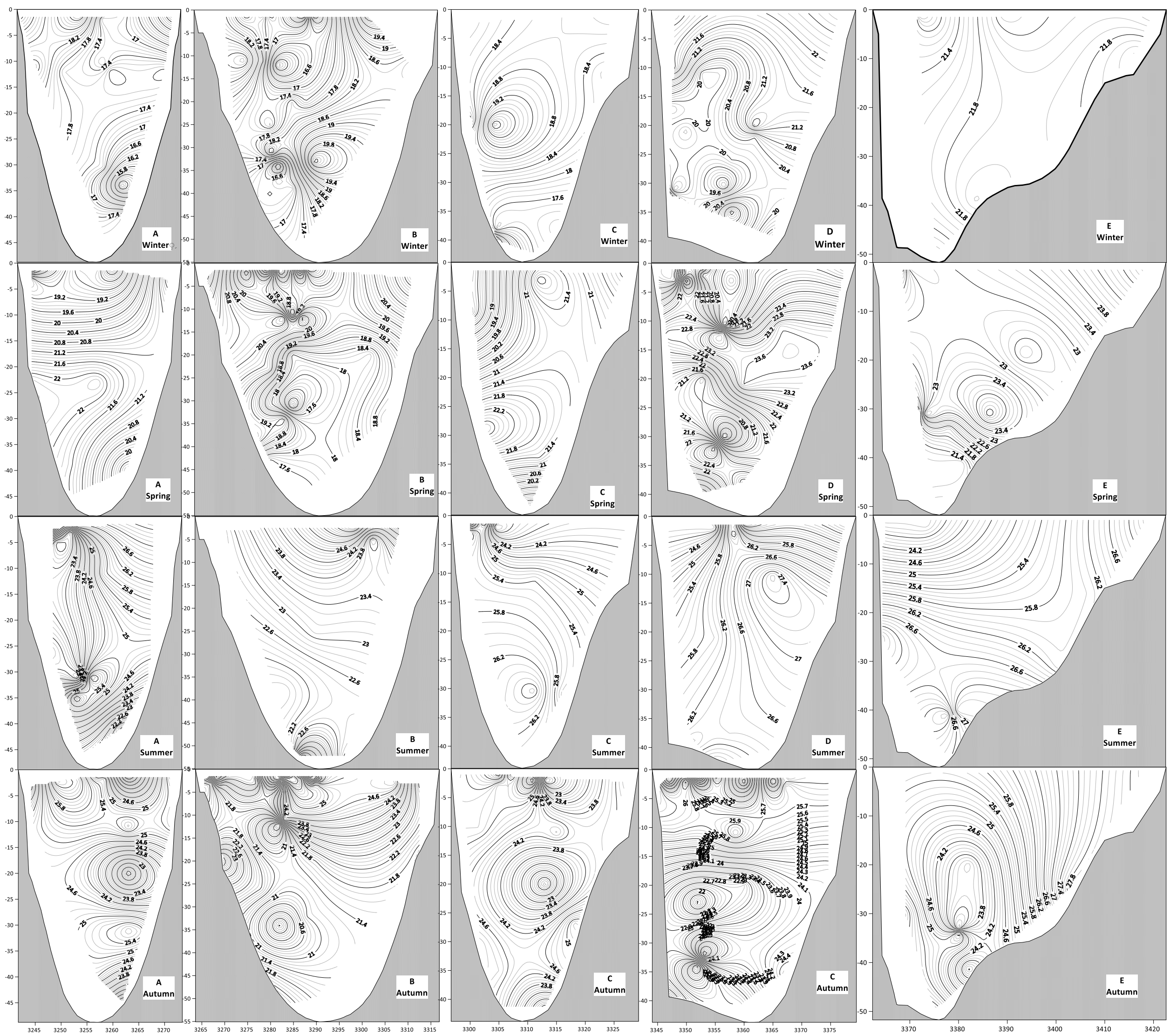

Fig. 6. The vertical water temperature distribution for the five sectors during winter, spring, summer and autumn

Eladawy*et al*. (2018) noted that the exchange through the Suez Canal is neglected since it is much smaller than the exchange across the Southern Gulf. Thus, the only opened border conditions are in the south of the Suez Gulf (Fig. 6). The group of islands scattered in the southern part of the gulf determines the course of the Red Sea currents, which interact with the Gulf of Suez. The water exchange between the Red sea and Suez Gulf occurs through the Strait of Gupal. Therefore, sector E is exposed to the largest changes in its water due to the exchange between both Red Sea water and gulf water (Fig. 6). This is strongly evident in winter, where temperatures rise in the middle of sector E and decreases to the east and west due to the impact of land cooling. Given that the gulf is located in a continental area, the intensity of the falling solar ray increases, the surface temperatures of the Gulf waters rise, especially in low-depth coastal areas. The water temperature rises in the eastern and western regions of sector E in the surface layer. It is notable that the gulf under investigation narrows and is less deep at sector D (fig. 6). The Red Sea currents extend into this sector and lead to warmer waters in the central region of the sector while a cooler bottom. The gulf's water course narrows at about halfway at the third sector C; the bottom water is hotter than the surface water (Fig. 6). At sector B, the surface water is hotter, and the middle of this sector has lower temperature values, affected by the exchange of water with sector A. In sector A, temperatures increase westward throughout the year except in the summer, where the surface layer gets hotter and drops downward in the westerly direction.

The diagrams of the monthly variation in surface, subsurface and near-bottom temperatures show that sector E is considered the hottest sector among all. This sector is affected by the mixing with the Red Sea hottest waters. Sector A has the lowest temperature values in winter and spring, while sector B shows the lowest in the summer and autumn seasons.

Several effects, either natural or human, affect the horizontal and vertical distribution of temperatures. In the south of the gulf, the effects of sea currents and gyers are obvious; these currents and gyers can affect the three layers, as well as reaching the next sector (F) **(Murray *et al*., 1982; Rady *et al*., 1998; Eladawy *et al.*, 2018; National Geospatial-Intelligence Agency, 2020)**. The variation in the atmospheric conditions has affected the variation in the sea surface temperatures of the gulf, where the intensity of solar radiation in the South is more severe than in the North **(Esbensen & Kushnir, 1981)**. Moreover, winds play a major role in generating the southern sea current from the gulf and generating the northern sea currents from the Red Sea, entering through the Jubal Strait, leading to the mixing of Red Sea waters with the waters of the Gulf of Suez **(Eladawy *et al.*, 2018)**. The northern area of the Gulf is under a lot of human activities which spills its sewage **(El Moselhy *et al.*, 2010; Khedr *et al.*, 2019)**.This affects the quality of the water of that shallow closed area, which is affected by the land cooling in the winter, due to very low air temperature and low solar rays, while rising somewhat in the summer and autumn.

Table 2. The average, max and min. of water temperature in the five sectors during winter, spring, summer and autumn

		Surface			Subsurface			Bottom		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
region A	Winter	17.35	17.78	17.10	17.34	17.51	17.10	17.27	17.38	17.19
	Spring	20.59	22.85	18.72	20.07	22.20	17.94	18.76	20.74	17.59
	Summer	25.94	27.04	24.94	25.63	26.43	24.32	23.21	24.09	22.10
	Autumn	22.93	24.62	21.25	23.55	25.85	21.25	22.33	24.74	19.92
region B	Winter	17.75	17.81	17.70	17.56	18.10	17.21	17.42	17.81	17.10
	Spring	21.20	22.57	18.77	20.50	22.01	18.52	19.27	20.39	18.02
	Summer	25.45	25.76	24.97	25.37	25.90	24.34	22.48	23.23	21.34
	Autumn	19.03	21.52	17.75	19.06	21.51	17.56	18.97	21.69	17.42
region C	Winter	18.67	20.00	17.98	19.24	22.17	17.70	17.28	17.54	17.02
	Spring	21.22	23.47	18.62	20.73	22.86	18.39	19.59	22.28	17.51
	Summer	25.84	26.40	25.05	25.56	26.30	24.40	23.22	24.15	22.20
	Autumn	20.22	21.97	18.67	20.92	22.17	19.24	19.07	22.38	17.28
region D	Winter	20.32	20.97	19.87	19.50	20.36	18.64	18.62	19.38	17.86
	Spring	22.46	23.35	20.86	22.33	23.60	20.49	21.90	22.73	20.38
	Summer	24.87	25.39	24.00	25.84	26.31	24.93	25.11	25.74	24.24
	Autumn	21.05	21.85	20.32	20.55	21.79	19.50	19.97	21.91	18.62
region E	Winter	21.50	21.90	20.94	21.11	21.50	20.76	20.06	20.86	19.61
	Spring	23.29	24.18	21.96	23.08	24.15	21.92	22.25	23.57	21.05
	Summer	26.77	27.32	25.92	26.41	27.06	25.82	25.67	26.86	23.88
	Autumn	22.77	24.90	21.50	22.68	25.42	21.11	21.86	24.66	20.06

CONCLUSION

In this study, the Suez Gulf is divided longitudinally into five areas; each area was half a degree long. Region E (southern area) recorded the highest water temperatures, whether in the surface, subsurface or bottom layers, averaging 27.32^{o}C (August), 27.33^{o}C (November) and 26.86^{o}C (August), respectively. Temperature differences in the three layers are very small, because this area (E) is open to the Red Sea, and there is a strong water circulation between the southern part of the gulfs and northern Red Sea. The vertical distribution of water temperature pointed to a rise in water temperature in the East of the sectors, decreasing westward. The variation of sea surface temperatures of the Suez Gulf, due to the intensity of solar radiation in the South, is more severe than in the

North. Winds also play a major role in generating the southern sea current from the gulf and generating northern sea currents from the Red Sea entering through the Jubal Strait. The northern area of the Gulf is exposed to a bundle of human activities, spilling its sewage, which in turn affects the quality of the water of that shallow closed area.

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