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The spatial and temporal monitoring of the sea surface temperature anomaly of the Strait of Hormuz

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ABSTRACT

Fertile coastal area is one of the challenges of marine science. This study identifies the upwelling areas in the Strait of Hormuz (52˚E to 59˚E, 23˚N to 28˚N) by using data satellite images of Sea Surface Temperature Anomaly (SSTA) in a period of 20 years (July 2002 - June 2021). It was selected four coastal stations named Lavan, Abu Musa, Qeshm, and Jask as a case study. The global monthly Multi-scale Ultra-high Resolution (MUR) of Sea Surface Temperature (SST) analysis anomaly by 0.01° resolution was used to find colder areas. The data were analyzed by Matlab. The satellite image results illustrated that the SSTA pattern showed both temporal and spatial fluctuations. The results of two decades of data showed well the spatial (between east-west and north-south) and temporal (August-November) fluctuations in the Strait of Hormuz. The Marine Heat Wave (MHW) started in June and made August the hottest month of the year. The duration of MHW was four months. While November was recognized as the coldest month in these two decades of data and SSTA of the curve of the strait reached less than -0.1°C. There was a permanent warm eddy (SSTA=0.2489°C) at 25.93°N and 53.23°E with a diameter of 55 km. Moreover, a permanent upwelling in Jask areas in the east of the Strait of Hormuz was confirmed.

1. Introduction

Upwelling is one of the most important phenomena in the transport of nutrients across the continental shelf [1]. There are different types of upwelling such as coastal upwelling and upwelled water by eddies. Both types can be temporary or permanent.

In the northern (southern) hemisphere, whenever the wind blows and the coast is on the left (right) side of the wind direction, the surface tension due to the Coriolis force causes Ekman mass transport along the perpendicular to the coast and towards the sea. In this case, the underwater replaces the surface water and the upwelling takes place [2]. If the divergence of water exists on the surface, especially on eddies, it will occur an upward current just because of the water shortage caused by diverging surface water [3]. In general, the popularity of upwelling in the coastal areas largely attributes to coastal upwelling that occurs due to winds driving the surface waters heading offshore that causing Sea Surface Temperature (hereafter SST) changes [4].

Downwelling is exactly the opposite. It occurs by the time the surface water shifts to the depth [3]. The maximum of up-/down-welling occurs when the wind is exactly parallel to the coastal line without any component perpendicular to the coast [5]. This up/down current can occurs in any place with the enough horizontal shear wind force. This transport volume of water can bring out necessary nutrients [6] especially chlorophyll [7] to the surface as the "Primary Production".

One way to find upwelled areas is the study of SST and its variations. Sea Surface Temperature Anomaly (hereafter SSTA) is one of the most important factors in the study of variations of SST. SSTA is used in the scientific researches by different targets, for example, precipitation [8], El Niño-Southern Oscillation (ENSO) [9], and even monsoon onset [10]. It is also illustrated the relationship between upwelled areas and the chlorophyll and SST cycles that the increase in phytoplankton biomass was driven by upwelling [11]. In the study of Southern Benguela Upwelling System, the Eastern Boundary Upwelling Systems (EBUS) were found to spatially cover approximately 1% of the ocean surface area, but account for approximately 20% of global fisheries production [12]. Interannual [13] and inter-seasonal [14] variability of equatorial eastern Indian Ocean upwelling was referred to SSTA. The above studies show the multiple use of SSTA in scientific research. This study shows colder areas than normal to find upwelling areas of the Strait of Hormuz.

2. Materials and Methods

2.1. The study area

The studied area was located on the Strait of Hormuz (box of Figure 1, from 52˚E to 59˚E, and from 23˚N to 28˚N), on the north of Arabian Sea, as an important waterway between Persian Gulf and Gulf of Oman. This waterway is one of the most important waterways in the world [15]. During peak times, every six minutes a ship passes through the Strait of Hormuz [16], and nearly 60% of the world's marine transport of oil comes from this region [15]. This area is of interest to researchers [17-32] due to its unique oceanographic features. The general circulation of Persian Gulf takes place in summer- and winter-time [15] but its strength is related to the prevailing wind [15]. The characteristics of circulation of Oman Gulf are [15]: 1- the outflow goes out of the bed of the Strait of Hormuz and it continues to the 200 m depth and spread inside the basin [31, 32]; 2- the anticyclonic eddies make cold upwelling along the Iranian coasts. It seems that the variations of SST are seasonal in Persian Gulf and they are related to the river inputs, general water circulation and weather systems [31].

2.2. Data analysis

Monthly Sea Surface Temperature anomaly (hereafter SSTA in °C) for twenty years (July 2002 to June 2021), obtained by satellite data [33]. The monthly free SSTA was downloaded as nc files. This product is a simple mean of the daily anomaly product created by ERD for a given month by the resolution of 0.01 degree [34]. The daily anomalies were created by ERD based on JPL MUR's climatology of Jet Propulsion Laboratory's (JPL) Multi-scale Ultra-high Resolution (MUR), merged, multi-sensor L4 v4.1. The foundation SST analysis product is a part of the Group for High-Resolution Sea Surface Temperature (GHRSST) project. SSTA had supported by the coastwatch website [33] and they were used in the current study.

Moreover, four stations on Iranian coasts (Lavan, Abu Musa, Qeshm, and Jask) were also selected for the comparisons with each other (Table 1).

Table 1. Stations Positions

No.	Station Name	Location	
		Latitude (˚N)	Longitude (˚E)
1	Lavan	26.80917	53.34833
2	Abu Musa	25.87417	55.01333
3	Qeshm	26.75194	55.89056
4	Jask	25.63778	57.76972

MATLAB software [35] was used to calculate and provide figures for the mean 20-year monthly, seasonally and annually SSTA.

4. Results and Discussion

Within the current research, the results of the twenty years (July 2002 to June 2021) average of the monthly SSTA is provided in figure 1. In this figure, negative SSTA values (blue color) mean colder than normal, and positive SSTA values (red color) mean warmer than normal. It is well seen that SSTA has temporal and spatial fluctuations. In December, the eastern side of the Strait of Hormuz is colder than the western side. This trend can also be seen in January and February. What is evident that in February and March there is the colder temperature of about 0.1ºC on the west side of the Strait of Hormuz near its southern shores, i.e. around the Arabian countries of the strait. This feature of being colder on the side of the Arabian coast, west of the strait, is also evident in May so that the west of the strait is about 0.1ºC colder than the east.

From June, a SSTA phase change occurs. Contrary to what May was a cold month in the west of the Strait of Hormuz, in July it becomes a warm part with the SSTA of more than 0.3ºC and a Marine Heat Wave (here after MHW) begins. MHWs have been observed in the world's oceans and regional seas [36–41]. The MHW of July spreads to the east of the strait in August, making August the hottest month of the year for the Strait of Hormuz (except for a small part near the Gulf of Oman). In August, in some places the SSTA difference even reaches more than 0.35°C. From September, the SSTA changes gradually and the marine heat intensity decreases so that November experiences the coldest SSTA with an anomaly less than 0.1 °C, especially in the east of the Strait of Hormuz.

This dipole characteristic of the Strait of Hormuz is not far from expectated. In the Sea Level Anomaly (hereafter SLA) study on 25 years of data (1993-2017) from the Persian Gulf, it has also been seen that the average monthly SLA is accompanied by a rise in October, November, December and a fall in the months of February, March, April and May [42]. and other months have been considered as transitional months. The minimum SLA happened in May and the maximum occurred in November. The spatial distribution of average monthly SLA was also reported to be fluctuating [42]. In other words, the relative symmetry between the months of summer (June and July) and winter (January and December) was seen as an example of dipole SLA [42].

Another notable point in figure 1 is the presence of a warm-core eddy of about 0.3°C around latitude of 26°N, which is well seen in five months, from December to April. In other months (May, June, July, August, September, October and November), the shape of this eddy with a warm core can be seen from a ring to a tongue form, which goes from Station 1 (Lavan) to Station 2 (Abu Musa). Even spite its shape change, its greater heat can be seen in this region in all months.

The maps (Figure 1) also show that in some months (especially January, April and May) between stations 3

(Qeshm) and 4 (Jask), colder SSTA can be seen on the inshore than the offshore, especially in the curve of the strait of Hormuz.

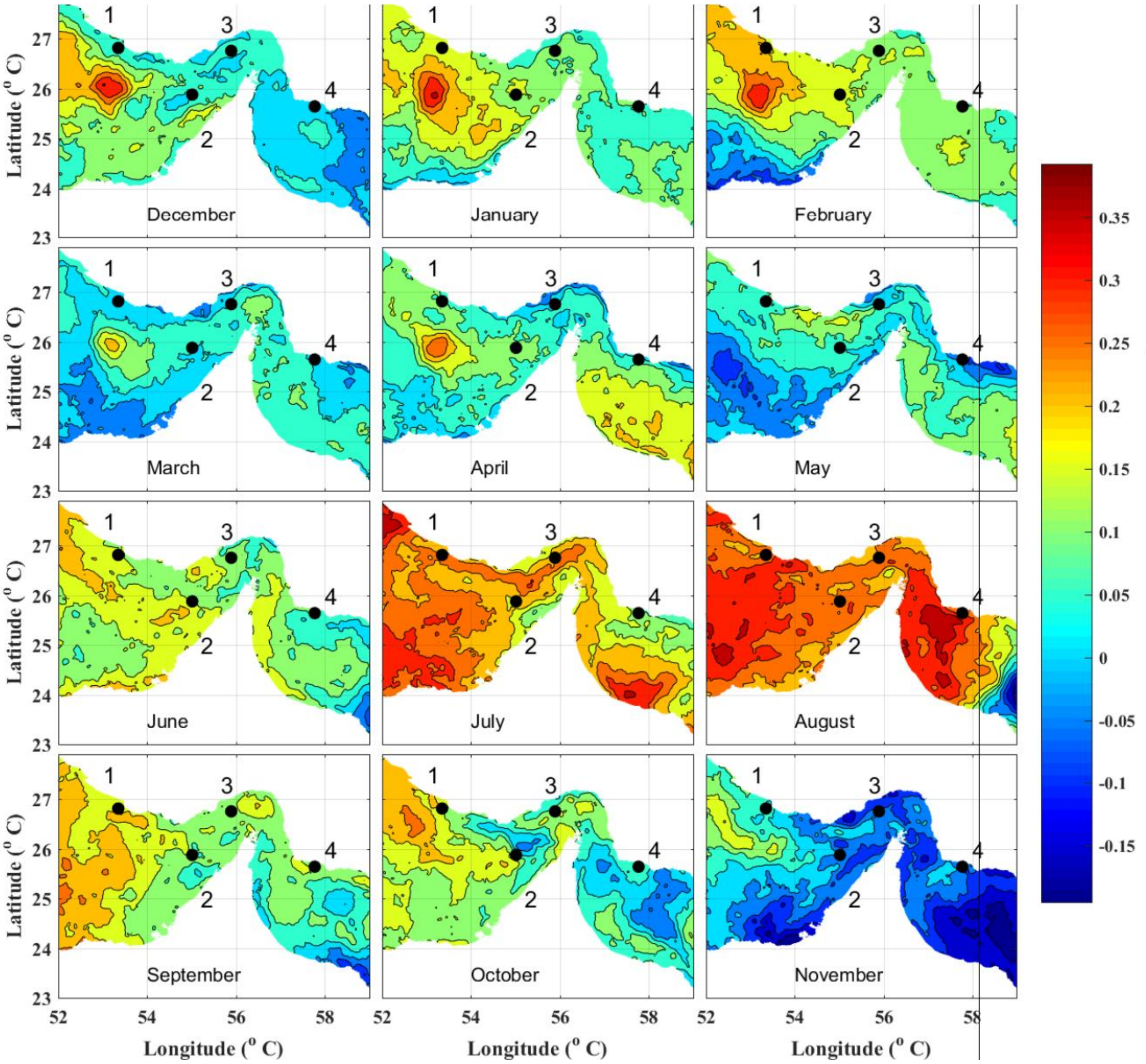

Figure 1. The 20-years mean of monthly SSTA in degrees of centigrade. Circles show the stations: (1) Lavan, (2) Abu Musa, 3) Qeshm and (4) Jask.

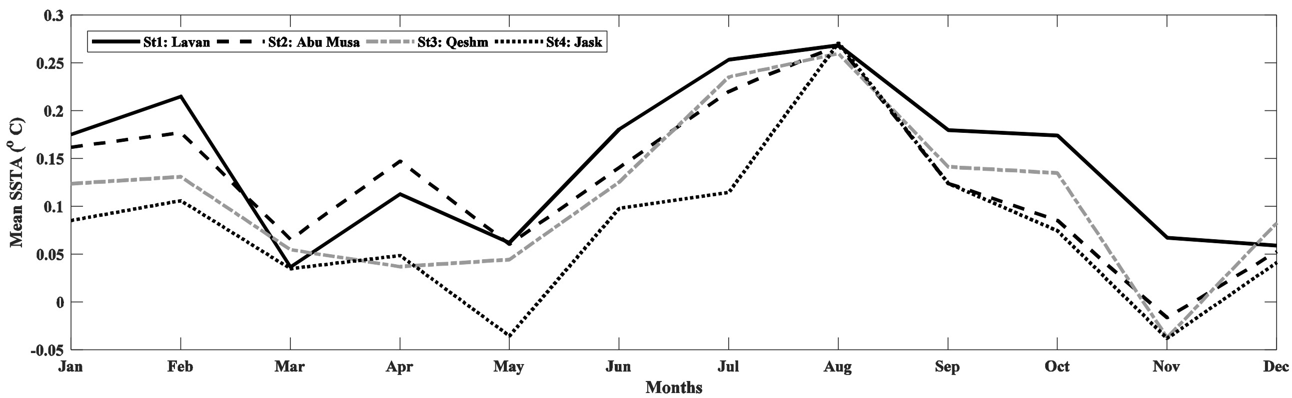

Figure 2. The 20-years mean of monthly SSTA in degrees of centigrade for the studied stations.

A closer look at the values of these stations (Figure 2) shows that station 4, Jask, experiences lower values of SSTA than the other stations in all months of the year, and even in the May and November, it reaches negative values of -0.035°C and -0.0382°C, respectively). But in August, it experiences warm SSTA again due to the MHW and reaches its peak. Among the selected stations, station 1 (Lavan), is the warmest station

compared to other stations and except for March and April, it experiences more SSTA in other months. August is again the warmest month of the year for all stations with an SSTA greater than 0.2°C.
November is also the coldest month of the year for three stations Abu Musa (Station 2), Qeshm (Station 3) and Jask (Station 4). For station 1 (Lavan), which is located west of the Strait of Hormuz, March is the coldest month with an SSTA value of 0.0364°C compared to November with a value of 0.0672°C. The SSTA difference between the eastern and western stations confirms the difference between the east and west of the Strait of Hormuz.
The annual mean SSTA from 20 years of data (2002-2021) shows that the SSTA value of station 4 (Jask) is 0.077°C while other stations are higher (Lavan=0.1485°C, Abu Musa=0.1238°C and Qeshm=0.1110°C). In Figure 3, it is also obvious blue colors near station 4, Jask, which matches well the upwelling near this station reported in other studies [15, 43] and the effects were also reported [44-47].

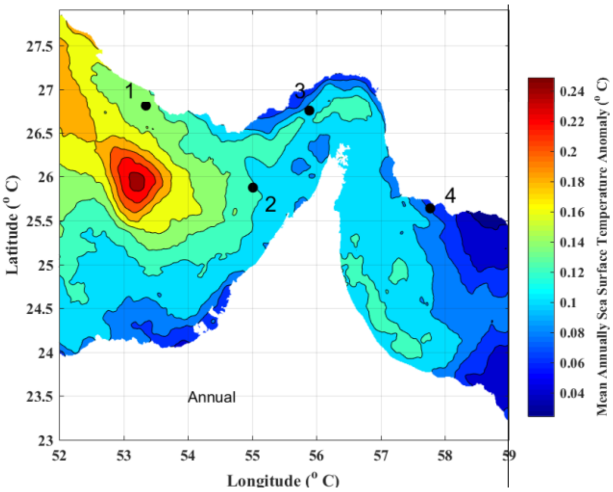

Figure 3. The annually mean (July 2002 to June 2021) of SSTA (°C). Circles show the stations of Table 1.

Figure 3 also approves the warm core of the eddy near the latitude of 26°N in the west of the Strait of Hormuz, with the exact central of 25.93°N and 53.23°E. which has a diameter of roughly 55.3 kilometers (0.5°). The existence of eddies has been confirmed in the previous study [48-49] by a diameter of roughly 50 km.

5. Conclusions

From the data of twenty years (2002-2021), it was concluded that the SSTA in the Strait of Hormuz has temporal and spatial changes. The MHW that started from the transition month in June and reached its peak in August will enter the transition month again in September. In other words, this MHW lasts strongly for four months, and in other months the Strait of Hormuz experiences less hot conditions. November is the only month when the Strait of Hormuz curve cools a little and the SSTA reaches less than -0.1°C. In other months, SSTAs for the curve of the Strait of Hormuz are more than zero. Also, the asymmetric dipole characteristic of SSTA can be seen between the east and west of the Strait of Hormuz. Although March and May are relatively cool months to the west of the Strait of Hormuz, December and November are cool months to the east of the strait. In addition, in this study, the existence of an eddy with a warm core at the latitude of 25.93°N and with an approximate radius of 55 km was confirmed.

List of Symbols

E	Longitude [in ˚]
MHW	Marine Heat Wave [in ˚C]
N	Latitude [in ˚]
SLA	Sea Level Anomaly [in m]
SST	Sea Surface Temperature [in ˚C]
SSTA	Sea Surface Temperature Anomaly [in ˚C]

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