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Upwelling events in the Caspian Sea

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Abstract

In this article, upwelling phenomena that are observed in the surface waters of the Caspian Sea were studied. For this purpose, we used data from MODIS-Aqua satellite observations in the infrared range of 11 microns, with a spatial resolution of 4 km, for the period 2003-2021, which are available through the NASA Giovanny on-line data system databases. It has been established that in the eastern part of the Middle and South Caspian, upwelling phenomena are mainly observed from May to September. The most intense upwelling is observed on the eastern coast of the Middle Caspian in July-August. According to averaged long-term data, the upwelling phenomenon during this period is mainly observed between 40-44º latitude, and its width increases from north to south, reaches 60-70 km in the direction of the Kazakh Gulf and decreases to the south. In the upwelling zone, the temperature gradient sometimes reaches 4.0ºC/100 km. In some years, the upwelling zone that has arisen on the eastern coasts can spread over long distances and even reach the western coasts. In most cases, the upwelling phenomenon occurs against the background of advection of warm waters from the South Caspian to the Middle Caspian.

1. Introduction

In the eastern and western coasts of the Middle and partly Southern Caspian, a thin strip of deep cold waters rises, which is called the upwelling phenomenon

The phenomenon of upwelling in the Caspian Sea and its causes are the subject of many scientific works. A number of researchers (Kosarev 1980) showed in their studies that the rise of deep waters to the surface is due to the water cycle under the influence of wind.

Thus, long-term studies show that easterly winds prevail over the eastern part of the Caspian Sea from mid-July to October (Dyakonov & Ibraev 2019). These winds drive relatively warm water from the sea surface into the open sea, and it is replaced by cold water rising to the surface from the deep layers.

On the other hand, currents directed from the shore to the open sea create reverse currents of water in the lower layers, i.e., currents of cold water directed towards the shore.

There are different explanations for the occurrence of upwelling. So, in the 1960s. it was suggested that groundwater is the cause of temperature anomalies in the eastern part of the Middle Caspian (Mayantsev & Osyanin 1965). One of the arguments against this idea is the observed homogeneity of salinity and other hydrochemical properties of the waters of the eastern part of the Middle Caspian.

In 1977 A.A. Karimov and N.T. Klevtsova put forward a hypothesis about the relationship between temperature anomalies and internal waves (Kerimov & Klevtsova, 1977). The study of temperature anomalies occurring in the western part of the Middle Caspian showed that they are of a "synoptic" nature (Monakhova & Akhmedova, 2010).

The upwelling phenomenon is observed both on the eastern and western coasts of the Middle and South Caspian. However, it should be noted that if on the east coast in May-September upwelling is systematic, then on the west coast it is relatively episodic. From this point of view, and since the study considered only long-term average monthly, average seasonal and average annual distributions, it is difficult to identify and study the manifestations of upwelling on the west coast based on the corresponding satellite images.

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2. Method

The present study used water surface temperature (SST) data (2003-2021) from the NASA Giovanni online information system database based on nighttime measurements of the MODIS radio spectrometer installed on the Aqua satellite. The MODIS spectroradiometer with a wavelength of 11 μm has a horizontal spatial resolution of 4 km, which makes it possible to detect mesoscale anomalies in the distribution of the surface temperature of the Caspian Sea, especially upwelling zones, and their characteristic features.

3. Results and discussion

As can be seen from Figure 1, the upwelling in May is not very intense, but the size and intensity of the upwelling zone in May in different years can be different (Ginzburg et al., 2020; Lavrova et al., 2011). Upwelling, which began mainly in the eastern part of the Middle Caspian in May, relatively weakens the advection of warm water mass from the South Caspian to the Middle Caspian.

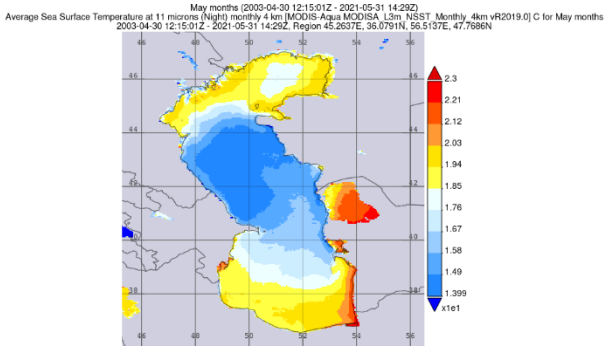

Figure 1. Distribution of sea surface temperature in the Caspian Sea in May

In June, the upwelling phenomenon, which began from the eastern coast of the sea, begins to manifest itself more clearly (Figure 2). Thus, the upwelling zone extends along the eastern part of the sea along the 20.2 ^{0}C isotherm from latitude 44,2^0 to 39,5^0 and covers large areas to the west. It can spread to the western coast of Ogurchink Island (Ginzburg et al., 2020). As can be seen from Figure 2, the minimum surface temperature in the up-welllling zone is 18 ^{0}C, but in some years it can drop to 14^{0}C.

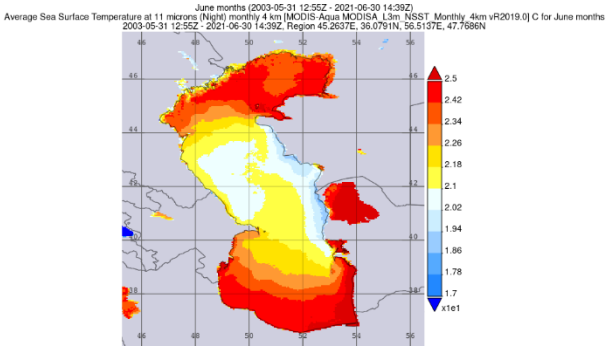

Figure 2. Distribution of sea surface temperature in the Caspian Sea in June

In June, the intensification of the upwelling phenomenon in the eastern part of the Middle and partly the South Caspian is accompanied by a noticeable weakening of the advection of warm water masses from the east of the South Caspian and its deviation to the west.

In July, a pronounced upwelling was recorded on the eastern coast of the Middle and partly Southern Caspian (Figure 3). As can be seen from the figure, the width of the upwelling zone increases from north to south, and in some places even reaches 60 km. In the east of the Middle Caspian, the water surface temperature drops from 25 ºC to 21 ºC from west to east. The temperature gradient is 4.2 ºC/100 km.

Figure 3 shows that the upwelling zone extends from the 40th parallel to the 44.5th parallel, expands to the south from Cape Peschany and even penetrates the South Caspian. Intense upwelling partially extinguishes the advection of warm water mass from the South Caspian to the Middle Caspian, and even the reverse process occurs, i.e., advection of the upwelling mass of cold water from the Middle Caspian to the South Caspian.

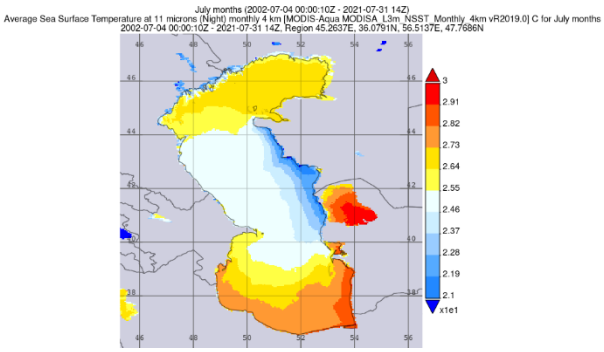

Figure 3. Distribution of sea surface temperature in the Caspian Sea in July

As can be seen from Figure 4, the upwelling process in August remains intense, but compared to July, its southern border shifts by about 0.5÷0.7º to the north, and the process cannot penetrate the South Caspian. As can be seen from the figure, the reason for this is the advection of warm waters from the South Caspian to the Middle Caspian more often than in July. In the western part of the South Caspian, on the contrary, advection of relatively cold waters from the Middle Caspian prevails. Lower upwelling temperatures (22 ºC) are observed in the area from the southern coast of Cape Peschanyi to the northern part of the Kazakh Bay.

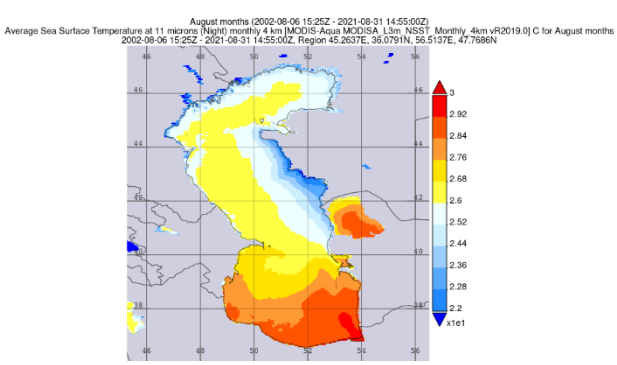

Figure 4. Distribution of sea surface temperature in the Caspian Sea in August

It should be noted that in some years the nature of the distribution of the average surface temperature in August may undergo certain changes. Figure 5 shows the distribution of the average sea surface temperature for August 2009 over the sea area. As can be seen, there is a strong advection of warm water masses from the eastern part of the South Caspian to the Middle Caspian, as evidenced by the convexity of the corresponding isotherms to the north. This process prevents the upwelling zone from spreading to the south. Instead, the rising cold-water mass extends to the west in a strip about 200 km long and about 100 km wide from the direction of Cape Peschany, and even individual jets of cold water reach the western coast.

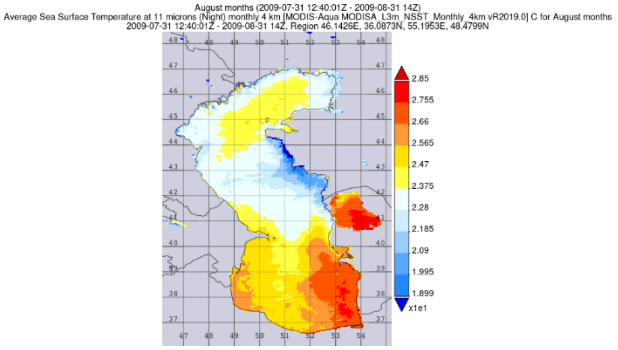

Figure 5. Distribution of the average water surface temperature in the Caspian Sea area in August 2009

The upwelling event, which took place in August 2014, is of greater interest due to its uniqueness. The distribution of the average surface temperature for August 2014 is shown in Figure 6. As can be seen from the Figure 6, the upwelling phenomenon here occurs under conditions of strong temperature advection, which originates in the eastern part of the South Caspian and is directed to the north, which prevents upwelling from spreading to the south. Temperature advection from the eastern part of the South Caspian to the north extends along the eastern coast of the Middle Caspian to the Kazakh Gulf, and therefore the southern border of the upwelling zone begins only from the northern coastal waters of this bay. From the north, the upwelling zone is limited by the southern coastal waters of the Tyube-Karagan peninsula.

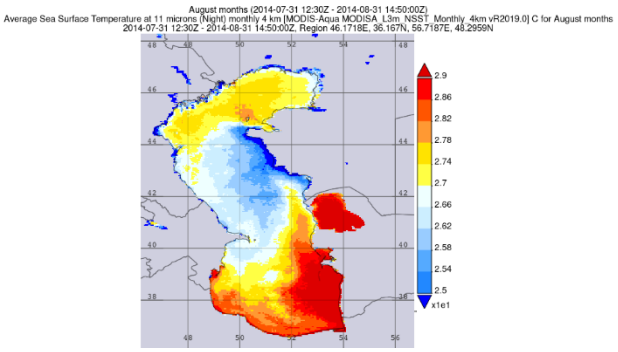

Figure 6. Distribution of the average water surface temperature in the Caspian Sea area in August 2014

As can be seen from Figure 6, the upwelling waters, which could not penetrate south from the Kazakh Gulf due to strong temperature advection from the southeast, spread to the west and south, reaching a very significant part of the Middle Caspian and even the northeastern coastal waters of the South Caspian, or rather the Azerbaijani sector of the sea. From this point of view, this effect can explain the sometimes-sharp cooling of the waters of the western coast of the sea during hot periods of the year. On the other hand, the penetration of upwelling waters into the South Caspian leads to anomalous changes in the distribution of surface waters here (Figure 6).

In September, the southern border of the upwell-ling zone in the east of the Caspian Sea (isotherm 22.6 ºC) passes through the latitude 40.5 º, as in August. Since the water temperature in the North Caspian begins to decrease in September, it becomes difficult to determine the northern boundary of the upwelling zone. The main difference between the upwelling observed in this month and August is that the upwelling zone is narrower, against the background of a relatively lower temperature.

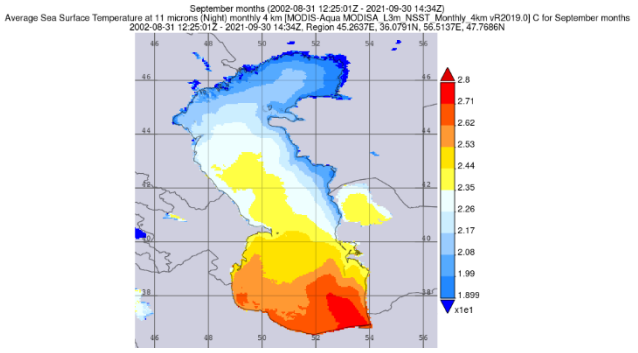

Figure 7. Distribution of sea surface temperature in the Caspian Sea in September

It should be noted that the upwelling processes observed in September of different years can manifest themselves in different ways. During the years of intense advection of warm water mass from the South Caspian to the Middle Caspian, the southern border of upwelling is significantly shifted to the north. For example, in September 2014, warm advective currents moving north along the east coast from the South Caspian extended to about the 42th parallel, preventing the upwelling process from spreading south, and instead, the transformed upwelling waters moved westward from the coastal zone to the direction to the south and reached a latitude of 38.5º in the South Caspian (Ginzburg et al., 2020). On the contrary, in years when there is no advection of the waters of the South Caspian into the Middle Caspian, the southern boundary of the upwelling belt can move up to the 40th parallel (Lavrova et al., 2011).

4. Conclusion

Analysis of MODIS Aqua data showed that in the period May-September, upwelling occurs in the eastern and western coastal waters of the Middle Caspian and partly in the South Caspian. It occurs regularly on the east coast, and fragmentarily on the west coast. The most intense upwelling is observed on the eastern coast of the Middle Caspian in July-August. According to averaged

long-term data, the upwelling phenomenon during this period is mainly observed between 40-44º latitude, and its width increases from north to south, reaches 60-70 km in the direction of the Kazakh Gulf and decreases to the south. In the upwelling zone, the temperature gradient sometimes reaches 4.0 ºC/100 km. In some years, the upwelling zone that has arisen on the eastern coasts can spread over long distances and even reach the western coasts. In most cases, the upwelling phenomenon occurs against the background of advection of warm waters from the South Caspian to the Middle Caspian.

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