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Research Article

The Spatio-Temporal Variation of Isothermal Water Mass in Jiaozhou Bay

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According to the survey materials of the waters of Jiaozhou in April and August 1981, the author determined the variation range of temperature, location, and the variation process of isothermal water mass in the waters of Jiaozhou Bay. The results showed that in April, high-temperature water masses were formed in the coastal waters of Jiaozhou Bay from the northeast to the northwest, and the water temperature reached 12.82–13.70°C, where the length of the interval of seawater temperature change was 0.88°C. In August, the high-temperature water masses were formed in the coastal waters of Jiaozhou Bay from the northwest to the north with the high temperature within 27.32–27.37°C, where the length of the interval was 0.05°C. In April and August, the high-temperature water masses were formed in the northern coastal waters where the depth was 1.00–5.00 m. The heat of high-temperature water masses was sourced from solar radiation energy. In August and in the coastal waters near the estuary of Haibo River, high-temperature water masses were formed, with a high water temperature of 28.00–30.90°C. The high temperature of the Haibo River provided heat to the waters of Jiaozhou Bay. In April, a circular low-temperature water mass was formed in the central waters of the bay, and the water temperature reached a low temperature of 7.52–8.51°C, which indicated that the central waters of the bay still maintained the uniform low temperature in winter and formed a low-temperature water mass. Therefore, the innovation of this paper is to put forward the spatio-temporal variation of the isothermal water mass in Jiaozhou Bay, established the block diagram of temperature changes in the waters of Jiaozhou Bay in April and August, and further elaborated the characteristics of isothermal water masses. (1) At the same time change, both the high-temperature water mass and the low-temperature water mass have stability. (2) In different time changes, whether it is a high-temperature water mass with a relatively higher water temperature or a high-temperature water mass with a very high water temperature, the water mass is stable.

1. Introduction

The ocean occupies 71% of the Earth's surface area. At the same time, the heat capacity of seawater greatly exceeds the heat capacity of land and air. Therefore, the ocean plays a great role in climate regulation on the entire Earth [1–10] to study the isothermal water mass in the coastal waters and its variation process benefits to the sustainable development of marine ecosystems. According to the survey materials in 1981, the author determined the temperature ranges, position, and variation process of isothermal water mass in the waters of Jiaozhou Bay and obtained the heat sources in the waters of Jiaozhou Bay and spatio-temporal variation process of isothermal water masses, providing the scientific theoretical basis for the study of water temperature changes in Jiaozhou Bay. The results showed that in April, high-temperature water masses were formed in the coastal waters of Jiaozhou Bay from the northeast to the northwest, and the water temperature reached 12.82–13.70°C, where the length of the interval of seawater temperature change was 0.88°C. In August, the high-temperature water masses were formed in the coastal waters of Jiaozhou Bay from the northwest to the north with the high temperature within 27.32–27.37°C, where the length of the interval was 0.05°C. In April and August, the high-temperature water masses were formed in the northern coastal waters where the depth was 1.00–5.00 m. The heat of high-temperature water masses was sourced from solar radiation energy. In August and in the coastal waters near the estuary of Haibo River, high-temperature water masses were formed, with a high water temperature of 28.00–30.90°C. The high temperature of Haibo River provided heat to the waters of Jiaozhou Bay. In April, a circular low-temperature water mass was formed in the central waters of the bay, and the water temperature reached a low temperature of 7.52–8.51°C, which indicated that the central waters of the bay still maintained the uniform low temperature in winter and formed a low-temperature water mass.

2. Survey Waters, Materials, and Methods

2.1. Natural Environment of Jiaozhou Bay. Jiaozhou Bay is located in the southern part of the Shandong Peninsula. Its geographical position is between 120°04′–120°23′E and 35°58′–36°18′N. It is bounded by the line connecting Tuan Island and Xuejia Island and is connected to the Yellow Sea. With an area of about 446 km^2 and an average water depth of about 7 m, it is a typical semienclosed bay. There are more than a dozen rivers entering the sea in Jiaozhou Bay, among which are the Dagu River, Yang River, the Haibo River, Licun River, and Loushan River in Qingdao City with larger runoff and sand content. These rivers are all seasonal rivers, and the river hydrological characteristics have obvious seasonal changes [11, 12].

2.2. Materials and Methods. The survey data of water temperature in the waters of Jiaozhou Bay in April and August 1981 used in this study are provided by the North Sea Monitoring Center of the State Oceanic Administration. In April, water samples are taken from 30 stations: A1, A2, A3, A4, A5, A6, A7, A8, B1, B2, B3, B4, B5, C1, C2, C3, C4, C5, C6, C7, C8, D1, D2, D3, D4, D5, D6, D7, D8, D9. In August, water samples are taken from 29 stations: A1, A2, A3, A4, A5, A6, A7, A8, B1, B3, B4, B5, C1, C2, C3, C4, C5, C6, C7, C8, D1, D2, D3, D4, D5, D6, D7, D8, D9 (Figure 1). Water samples were taken according to the water depth (surface and bottom layers were taken when the depth >10 m, and only the surface layer was taken when the depth <10 m) for investigation and sampling. The survey of water temperature in Jiaozhou Bay water body was carried out according to the national standard method, which was recorded in the national "Marine Monitoring Code" (1991) [13].

3. Results

3.1. The Definition of Yang Dongfang Water Mass and Isothermal Water Mass. The concept of water mass proposed by Yang Dongfang refers to a water body composed of a certain point or two points or multiple points, which have a certain common feature, which is called a water mass with a certain feature [14–18]. The definition of this water mass is proposed by the author to distinguish it from other concepts of water mass. It can be called the Yang Dongfang water mass. Yang Dongfang further proposed the concept of the isothermal water mass, which is defined as compared with the surrounding waters, a water body centered on a certain water area that has a relatively similar temperature. The

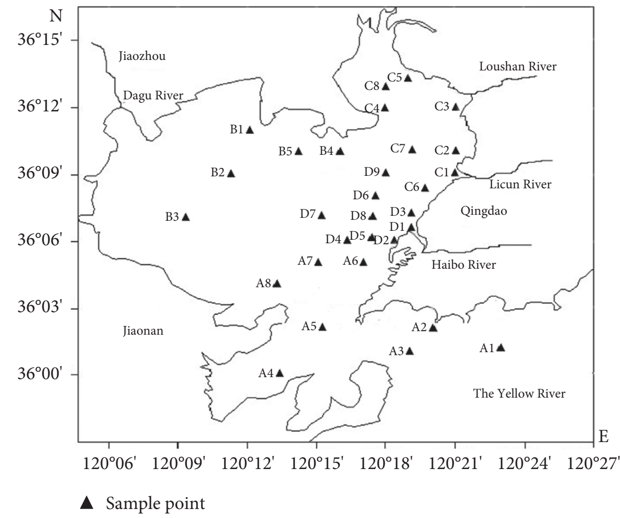

Figure 1: Investigation site of Jiaozhou Bay.

water body of this water area is called Yang Dongfang isothermal water mass or isothermal water mass for short. For Yang Dongfang isothermal water mass, if the water temperature of the water mass is relatively high, it is called Yang Dongfang high-temperature water mass; if the water temperature of the water mass is relatively low, it is called Yang Dongfang low-temperature water mass; compared with other water temperatures, if the water temperature of the water mass is the median, it is called Yang Dongfang medium-temperature water mass [19–25].

3.2. Yang DongFang High-Temperature Water Mass. In April, in the northeastern of Jiaozhou Bay, at station C3 in the coastal waters of the estuary of Loushan River and station C5 in the coastal waters, and at station B1 in the coastal waters of the northwest, that is, from the northeast along the northern coastal waters to the northwest, the water temperature reached [26–33] 12.82–13.70°C, and a high-temperature zone was formed with the northern coastal waters as the center. According to the definition of Yang Dongfang isothermal water mass, there was a high-temperature water mass in the waters of Jiaozhou Bay (Figure 2), located in the coastal waters from the northeast to the northwest. In this high-temperature water mass, the length of the interval of seawater temperature change was 0.88°C.

In August, at station B1 in the northwestern coastal waters and at station B4 in the northern coastal waters, that is, in the coastal waters from the northwest to the north, the water temperature reached a relatively high of 27.32–27.37°C, and a high-temperature zone was formed with the coastal waters from northwest to the north as the center. According to the definition of Yang DongFang isothermal water mass, there was a high-temperature water mass in the waters of Jiaozhou Bay (Figure 3), located in the coastal waters from northwest to the north. In this high-temperature water mass, the length of the interval of seawater temperature change was 0.05°C [34–40].

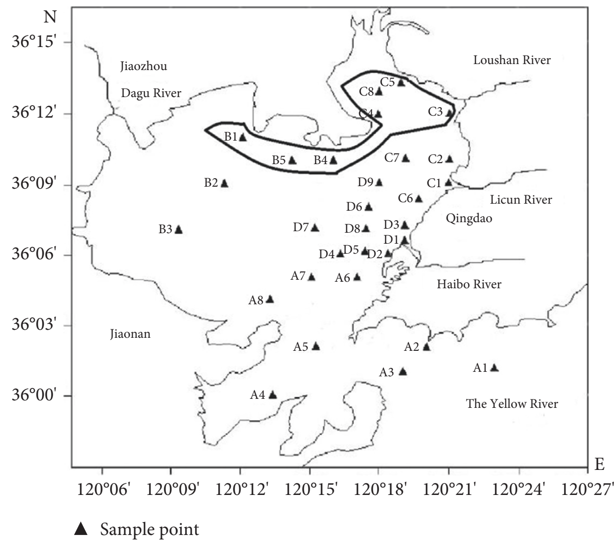

Figure 2: High-temperature water mass in the surface waters in April (°C).

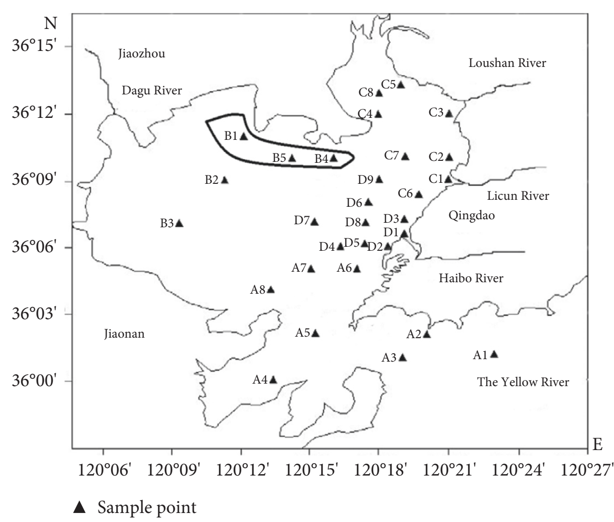

Figure 3: High-temperature water mass in the surface waters in August (°C).

In August, in the east of Jiaozhou Bay, at station D1 in the coastal waters of the estuary of Haibo River, the water temperature reached a relatively high of 30.90°C, and a high-temperature zone was formed with the coastal waters of the estuary of Haibo River as the center. According to the definition of Yang Dongfang isothermal water mass, there was a high-temperature water mass in the waters of Jiaozhou Bay (Figure 4), located in the coastal waters of the estuary of Haibo River. In this high-temperature water mass, the length of the interval of seawater temperature change was 2.90°C.

3.3. Yang Dongfang Low-Temperature Water Mass. In April, centering on station D7 in the central waters of the bay, covering stations A7 and D4 constituted a circular water area [41–45]. The water temperature reached a low temperature of 7.52–8.51°C, forming a low-temperature zone. In this way,

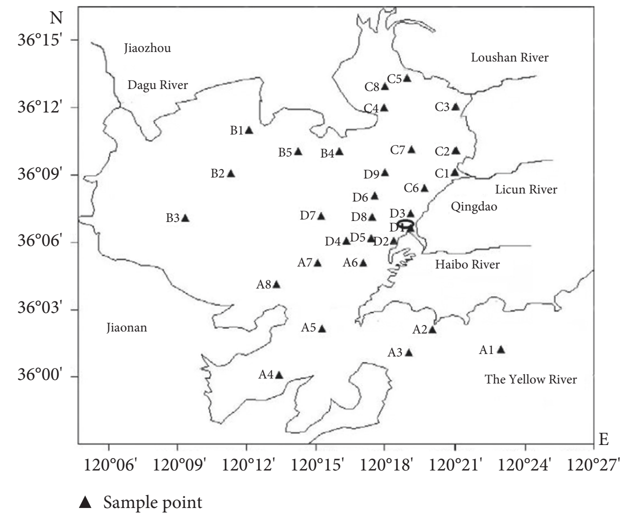

Figure 4: High-temperature water mass in the estuary of the river in Jiaozhou Bay in August 1981.

a closed-loop low-temperature zone appeared, the temperature of which was 7.52~8.51°C (Figure 5). According to the definition of Yang Dongfang isothermal water mass, there was a low-temperature water mass in the central waters of Jiaozhou Bay (Figure 5), located in the central waters of the bay. In this low-temperature water mass, the length of the interval of sea-water temperature change was 0.99°C.

4. Discussion

4.1. The Heat Sourced from Solar Radiation Energy. In April, a high-temperature water mass was formed in the coastal waters from the northeast to the northwest of Jiaozhou Bay [46–52]. In this high-temperature water mass, the water temperature reached a relatively high 12.82–13.70°C, and the length of the interval of water temperature change was 0.88°C. Moreover, this high-temperature water mass was in nearshore waters with a water depth of 1.00 to 5.00 meters.

In August, a high-temperature water mass was formed in the coastal waters from the northwest to the north of Jiaozhou Bay. In this high-temperature water mass, the water temperature reached a relatively high 27.32–27.37°C, and the length of the interval of water temperature change was 0.05°C. Moreover, this high-temperature water mass was in nearshore waters with a water depth of 2.00 to 5.00 meters.

The energy obtained by the Earth mainly comes from the sun. When seawater absorbs heat, short-wave radiation from the sun and long-wave radiation from the atmosphere bring heat to the sea. For the total solar radiation energy reaching the sea surface, coastal seawater can absorb up to 77.2% of the energy within one meter of the surface, and within 10 meters of the surface, the energy absorbed by the coastal seawater is as high as 99.6% [1]. In April and August, the high-temperature water masses were in the northern coastal waters of Jiaozhou Bay, with a water depth of 1.00 to 5.00 meters. Then, the heat source of the high-temperature water mass came from the total solar radiation energy, and the energy absorbed by the water body can reach more than

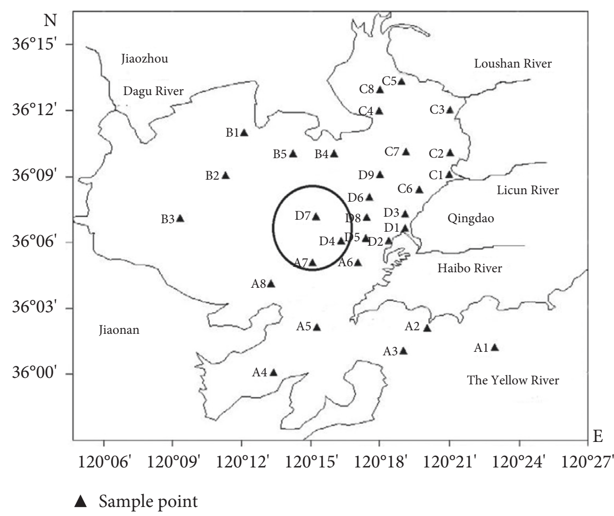

Figure 5: Low-temperature water mass in the central waters in April (°C).

80.0%. In this way, the heat source of the entire Jiaozhou Bay waters came from the northern coastal waters, and the northern coastal waters were heated by solar radiation energy.

4.2. Heat Source Input by River. In August, a high-temperature water mass was formed in the coastal waters of the estuary of Haibo River in the east of Jiaozhou Bay. In this high-temperature water mass, the water temperature reached a relatively high 28.00–30.90°C, and the length of the interval of water temperature change was 2.90°C. Moreover, this high-temperature water mass was in nearshore waters of the estuary of Haibo River with a water depth of 2.00 to 2.20 meters.

In August, solar radiation energy provided a lot of heat to the river. As the river flowed continuously, the total solar radiation heated up continuously. When the river reached the coastal waters of the estuary, the water temperature of the river was very high. When the river entered the coastal waters of the estuary, the water temperature reached the highest temperature of 30.90°C in the entire waters of Jiaozhou Bay. Therefore, in August, the river brought the high temperature to provide heat to the waters of Jiaozhou Bay.

4.3. The Formation Process of Low-Temperature Water Mass. In April, in the central water area of the bay, a circular water area was formed with this water area as the center, and a low-temperature water mass was formed. In this low-temperature water mass, the water temperature reached a low temperature of 7.52–8.51°C, and the length of the interval of seawater temperature change was 0.99°C. And this low-temperature water mass was in the central waters of the bay, with a water depth of 7.50–21.00 meters [47–50].

In winter, the entire sea area is controlled by the polar continental air mass, and strong northerly winds blow continuously over the sea. The seawater cools rapidly and evaporates strongly, with a strong vortex mix and convection mix, making the temperature from the sea surface to the seabed in many shallow water areas uniform [1]. With the end of winter and the advent of spring, the weather began to warm, and the total solar radiation energy began to gradually increase. As a result, in April, in the coastal waters of Jiaozhou Bay from the northeast to the northwest, where the water depth was 1.00 to 5.00 meters, it formed a high-temperature water mass. In the central waters of the bay, the water depth was 7.50–21.00 meters, and there was no heat source to provide heat to the central waters of the bay. In this way, the central waters of the bay still maintained the uniform low temperature in winter, forming a low-temperature water mass.

4.4. The Spatio-Temporal Variation of Isothermal Water Mass. The shape of the bay is like half a pot. In April, in the coastal waters of Jiaozhou Bay from the northeast to the northwest, the water depth was 1.00 to 5.00 meters. The solar radiation energy heated this water area, resulting in the rise of water temperature, 12.82–13.70°C, and forming a high-temperature water mass. The length of the interval of seawater temperature change was 0.88°C. It is like adding firewood to half a pot, and the temperature rises on the edge of the pot. The high-temperature water in the shallow water area cannot transfer heat to the central waters of the bay in time, and the water depth was 7.50–21.00 meters. In this way, there was no heat source to provide heat to the central waters of the bay. As a result, the central waters of the bay still maintained a uniform low temperature in winter, and the water temperature reached 7.52–8.51°C, forming a low-temperature water mass. The length of the interval of seawater temperature change was 0.99°C (Figure 6).

In August, solar radiation energy continued to heat this high-temperature water mass, causing the temperature of this high-temperature water mass to continue to rise, and the water temperature reached a higher 27.32–27.37°C. The length of the interval of seawater temperature change was 0.05°C. It is like adding firewood to half of the pot, and the temperature continues to rise on the edge of the pot. At the same time, the water temperature brought by the river at the estuary of the bay reached 30.90°C, which is the highest temperature in the entire waters of Jiaozhou Bay. As a result, in the coastal waters near the estuary of Haibo River, where the water depth was 2.00 to 2.20 meters, the high temperature of the river provided heat to the Jiaozhou Bay waters, resulting in the formation of high-temperature water mass in the coastal waters near the estuary of Haibo River, where the water temperature reached 28.00–30.90°C, and the length of the interval of seawater temperature change was 2.90°C. This is like sending a high-temperature stream of water to half of the pot, causing the edge of the pot to continue to rise in temperature. Moreover, in April, the low-temperature water mass formed in the central waters of the bay gradually turned into a medium-temperature water mass by August, and part of the heat of this water mass was transported to the outside of the bay. Here shows the variation process of the water mass in the center of the bay (Figure 7).

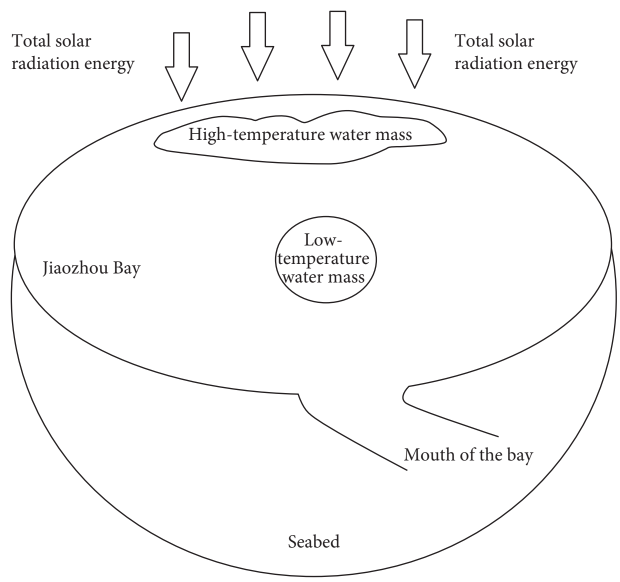

Figure 6: The block diagram of heat transfer of water temperature in April.

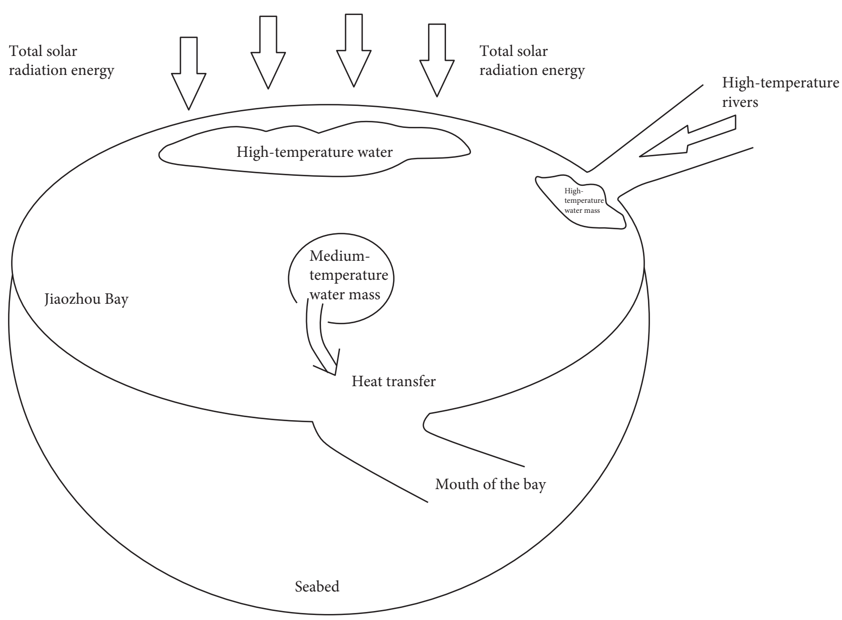

Figure 7: The block diagram of heat transfer of water temperature in August.

4.5. The Feature of Isothermal Water Mass. In April, the length of the interval of water temperature change in the high-temperature water mass was 0.88°C, which did not exceed 1.00°C. This showed that the high-temperature water mass was stable. The length of the interval of water temperature change of the low-temperature water mass was 0.99°C, which did not exceed 1.00°C, indicating that the low-temperature water mass was stable. Then, at the same time change, both the high-temperature water mass and the low-temperature water mass have stability.

In April, although the high-temperature water mass was very close to the low-temperature water mass, the water temperature of the high-temperature water mass was 12.82–13.70°C, and the water temperature of the low-temperature water mass was 7.52–8.51°C. It can be seen that the high-temperature water mass did not transfer the heat quickly to the low-temperature water mass.

In April, the water temperature of the high-temperature water mass reached a relatively high 12.82–13.70°C, and the length of the interval of water temperature change was 0.88°C, which did not exceed 1.00°C. This indicated that the high-temperature water mass with higher water temperature was stable. In August, in the high-temperature water mass, the water temperature reached a much higher 27.32~27.37°C, and the length of the interval of the water temperature change was 0.05°C, not exceeding 1.00°C. This showed that the high-temperature water mass with much higher water temperature was also stable. Then, in different time changes, both the high-temperature water mass with high water temperature and the high-temperature water mass with much higher water temperature have stability.

5. Conclusion

In April, a high-temperature water mass was formed in the coastal waters from the northeast to the northwest of Jiaozhou Bay. In this high-temperature water mass, the water temperature reached a relatively high 12.82–13.70°C, and the length of the interval of water temperature change was 0.88°C. Moreover, this high-temperature water mass was in nearshore waters with a water depth of 1.00 to 5.00 meters. In August, a high-temperature water mass was formed in the coastal waters from the northwest to the north of Jiaozhou Bay. In this high-temperature water mass, the water temperature reached a relatively high 27.32–27.37°C, and the length of the interval of water temperature change was 0.05°C. Moreover, this high-temperature water mass was in nearshore waters with a water depth of 2.00 to 5.00 meters.

In April and August, the high-temperature water masses were in the northern coastal waters of Jiaozhou Bay, with a water depth of 1.00 to 5.00 meters. Then, the heat source of the high-temperature water mass came from the total solar radiation energy, and the energy absorbed by the water body can reach more than 80.0%. In this way, the heat source of the entire Jiaozhou Bay waters came from the northern coastal waters, and the northern coastal waters were heated by solar radiation energy.

In August, a high-temperature water mass was formed in the coastal waters of the estuary of Haibo River in the east of Jiaozhou Bay. In this high-temperature water mass, the water temperature reached a relatively high 28.00–30.90°C, and the length of the interval of water temperature change was 2.90°C. Moreover, this high-temperature water mass was in nearshore waters of the estuary of Haibo River with a water depth of 2.00 to 2.20 meters. With the high temperature, Haibo River supplied heat to the waters of Jiaozhou Bay.

In April, in the central water area of the bay, a circular water area was formed with this water area as the center, and a low-temperature water mass was formed. In this low-temperature water mass, the water temperature reached a low temperature of 7.52–8.51°C, and the length of the interval of seawater temperature change was 0.99°C. And this low-temperature water mass was in the central waters of the bay, with a water depth of 7.50–21.00 meters. There are no heat sources providing heat to the central waters of the bay. Thus, the central waters of the bay still maintained the uniform low temperature in winter and formed a low-temperature water mass.

In April, in the coastal waters of Jiaozhou Bay from the northeast to the northwest, the water depth was 1.00 to 5.00 meters. The solar radiation energy heated this water area, resulting in the rise of water temperature and forming a high-temperature water mass. However, the water with high temperature cannot transfer the heat immediately to the central waters of the bay. As a result, the central waters of the bay still maintained the uniform low temperature in winter and formed a low-temperature water mass. In August, solar radiation energy continued to heat this high-temperature water mass, causing the temperature of this high-temperature water mass to continue to rise. At the same time, in the coastal waters of the estuary of Haibo River, the river with high temperature supplied heat to the waters of Jiaozhou Bay, resulting in the formation of a high-temperature water mass in the coastal waters of the estuary of Haibo River. In addition, in April, the low-temperature water mass formed in the central waters of the bay gradually turned into a medium-temperature water mass by August, and part of the heat of this water mass was transported to the outside of the bay. Therefore, the author established the block diagram of the temperature changes in the waters of Jiaozhou Bay in April and August, presented the spatio-temporal variation process of isothermal water mass in Jiaozhou Bay, and elaborated the features of isothermal water mass: (1) in the same time change, both the high-temperature water mass and the low-temperature water mass have stability. (2) In different time changes, whether it is a high-temperature water mass with a relatively higher water temperature or a high-temperature water mass with a very high water temperature, the water mass is stable.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no competing interests.

An earlier version of the paper has been presented at WCHBE 2021.

Acknowledgments

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