Climatic Zoning of SST in the East China Sea and Adjacent Seas from 1981 to 2010

Xiangchun Meng1, Jiancheng Kang1* and Xin Wang1

1School of Environmental and Geographical Sciences, Shanghai Normal University, Shanghai, 200234, China

*Corresponding author’s e-mail: kangjc@126.com

Abstract. In this study, the data of sea surface temperature (SST) and current for 1981 to 2010 from the SODA_2.2.4 were used to analyze the climatic zoning characteristics of SST in the East China Sea and adjacent sea areas, and the relationship between SST and relevant factors, to provide a reference for further research on long-term climate change. The results show that: (1) Under the combined action of sea-land distribution, latitude and ocean current, the study area can be divided into three climatic zones: the continental shelf area of the East China Sea, the Kuroshio area of the East China Sea and the Northwest Pacific Ocean. SST from northwest to southeast presents a low-high-second high distribution pattern. (2) Due to the influence of the change of direct point of the sun, the highest SST in the low and high latitudes is 1 month apart, which is July and August respectively. In general, the isotherm in the study area is dense in February. The average SST in the whole region was the lowest, about 19.9°C. The temperature difference between North and South is large, about 17°C. August isotherms are sparse; the average SST in the whole area is the highest, about 28.5°C; the temperature difference between north and south is small, about 6°C. (3) The annual temperature difference of the surface waters of the whole study area is related to latitude. Compared with the latitude, the annual temperature difference in the continental shelf area is the largest, and the Kuroshio area is the smallest. According to coefficient of variation of monthly SST, the annual variation of SST decreases from northwest to southeast. (4) SST rises fastest in May, June and July; and declines fastest in December and January. High-latitude sea areas and near-shore sea areas have rapid and larger changes in SST, and the Kuroshio affected area has slower and smaller changes.

1. Introduction

Climate change is occurring all over the world, and the atmosphere and oceans have warmed[1]; Climate change has become one of the most serious global environmental problems facing human society today[2], posing an urgent challenge to environmental management[3].

In order to promote the research on climate change, the World Meteorological Organization (WMO) climatology Committee formally proposed in 2015 that the 30 years between 1981 and 2010 should be taken as the latest benchmark for climate change comparative study (https://www.wmo.int/pages/mediacentre/press_releases/pr_997_en.html).

As an important part of the climate system, the ocean plays a crucial role in the energy and material balances of the climate system[4].

SST is an important physical parameter reflecting heat and water vapor exchanges on the sea surface, and it is also an intuitive characterization parameter of marine physical processes such as ocean circulation, ocean wind, ocean water mass and sea water mixing[5].
The East China Sea and its adjacent seas, includes the East China Sea and the Northwest Pacific Ocean, there are a wide continental shelf, complex terrain, variable coastal runoffs, and different north-south climate zones. Therefore, they have unique regional oceanographic characteristics and are one of the main areas affecting China's climate[6-8]. The eastern coastal provinces are the most economically developed and densely populated areas in China. It is extremely important and urgent to find out the distribution characteristics of SST over the East China Sea and adjacent waters in the new climatic baseline period (1981-2010) for China's coastal and even East Asia to cope with the challenges brought by climate change.

Previous studies have been conducted on the East China Sea and the adjacent sea areas, mainly focusing on a single climate index (SST) or the Kuroshio[9-14], but lacking studies on the spatial and temporal distribution characteristics, inter-monthly variations and influence mechanism of SST in the new climate base period (1981-2010).

In this study, SST data and sea current data in the new climate base period were used to comprehensively divide the climate region, and the average distribution characteristics and monthly variations of SST in each climate region were explored, laying a foundation for the study of regional climate change process, spatial differentiation and influence mechanism, as well as the prediction of future climate and environmental changes.

2. Research area and data source

The study area in this paper is the East China Sea and its adjacent waters, with the ranges of 21.25°N-33.25°N and 116.25°E-134.25°E, as shown in Figure 1.

![Figure 1. Schematic diagram of the study area (color bar represents seawater depth (m)).](image)

In addition to factors such as latitude and differences in the thermal properties of land and sea, complex topography and changeable ocean currents also have an important impact on SST. Therefore, SST, flow field and terrain data are used in this study.

Sea surface temperature (SST) data and flow field data come from the Global Simple Ocean Data Assimilation System (SODA_2.2.4) developed jointly by the University of Maryland and Texas A & M University[15]. This set of data uses the products of v2.0 reanalyzing wind field data in the 20th century (NOAA 20th century reanalysis v2, CR20v2)[16], and adopts the theory of random continuous estimation and quality control methods, including difference test, 4DVAR, KF, "prediction observation value", proximity point test, etc. Compared with the data of the same type, the horizontal spatial grid density is higher, the time scale is longer, and the error control method is more scientific[17]. Since its releases, it has received more recognition from research peers, which can meet the needs of this study. Data website: http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=4901. The time range selected in this article is 360 months from January 1981 to December 2010, and the space ranges are 21.25°N-33.25°N, 116.25°E-134.25°E.
3. Characteristics of SST and ocean current

3.1. Distribution characteristics of SST and current in the new climate base period (1981-2010)

SST and ocean current data from 1981 to 2010 in the data set from SODA were extracted and averaged annually. Then the annual average temperature of climate state and ocean current were superimposed to obtain the distribution map of climate state SST and ocean current in the East China Sea and adjacent waters, as shown in figure 2.

Figure 2. Distribution of mean SST and ocean currents over the East China Sea and adjacent waters from 1981 to 2010 (Isotherms are spaced 0.5℃; the direction of the arrow indicates the direction of the ocean current, and the length of the arrow indicates the velocity of the current).

Combined with figures 1 and 2, the study area can be divided into three parts according to the latitude, topographic characteristics and SST distribution at the study area. The west part of the study area is the low temperature area of the East China Sea continental shelf, the middle part is the warm tongue area of the Kuroshio in the East China Sea extending from the southwest to the northeast, and the east part is the Northwest Pacific sea area. It can be seen from the average flow direction of the current in 30 years that the Kuroshio is a stable current flowing through the eastern Taiwan and Okinawa Trough and into the Pacific Ocean through the Tugara Strait in the southwest of Japan. Combined with the isotherm distribution, it can be seen that the SST in the Kuroshio area is relatively high, and the isotherm is obviously bent to the northeast, indicating that the Kuroshio has a great influence on the distribution and trend of the isotherm in the Central Sea Area of the study area. As the branches of the Kuroshio, the Taiwan warm current and Tsushima warm current also have a significant impact on the distribution of regional isotherms.

In the continental shelf waters, SST ranges from 16℃ to 24.5℃, with a temperature difference of 8.5℃. The highest temperature is between 24 and 24.5℃, and it is located in a strip-shaped area at 23°N, 117°E to 30°N, and 128°E (the Kuroshio boundary area). The lowest temperature is between 16-16.5℃, and it is located in the control area of the northern Jiangsu coastal current (near 33.25°N, 122.75°E). The temperature increases from northwest to southeast along the continental shelf of the East China Sea. In the continental shelf (from 26.23°N, 122.75°E to 33.25°N, 122.75°E), the temperature gradient is large. There are 16 isotherms at 7 latitudes, and the isotherms are dense.

In the Kuroshio area, the surface temperature range is between 24.5-28℃, and the temperature difference is 3.5℃. The highest temperature is between 27.5-28℃, located at 21.25°N, 121.25°E, near the entrance of the Kuroshio. The lowest temperature is between 24.5-25℃, located at 29.75°N, 130.75°E, near the exit of the Kuroshio. The temperature decreases along the Kuroshio axis from
southwest to northeast. The isotherm is tongue-shaped, with a northeast-southwest trend. The axis is near 24.75°N, 123.25°E to 29.75°N, 130.75°E, and the angle between the axis and the latitude is about 45 degrees. The horizontal gradient of temperature change is relatively large on the northwest side of the Kuroshio axis in the East China Sea, and the distribution of isotherms is relatively dense; the horizontal gradient of temperature change is relatively small on the southeast side of the axis, and the isotherms are relatively sparse.

In the northwest Pacific, SST ranges from 23.5℃ to 27.5℃, with a temperature difference of 4℃. The isotherms are distributed in bands, and their directions are approximately parallel to the latitude. The horizontal gradient of temperature change is smaller than that in the continental shelf area (8 isotherms at 11 latitudes), and the distribution of isotherms is sparse.

In general, the SST of the study area showed a low-high-higher trend from the continental shelf area to the Kuroshio area, then to the Northwest Pacific. The surface seawater isotherms are densely distributed in the continental shelf area, and sparse in the Kuroshio area and the Northwest Pacific.

3.2. Monthly characteristics of SST and ocean current

In order to explore the characteristics of the monthly SST variation in the study area from 1981 to 2010, the monthly SST histogram in the study area was drawn by using the monthly average temperature and the difference between the maximum and minimum values in the study area, so as to visually demonstrate the law of the monthly SST variation in the study area (Figure 3).

![Figure 3. Histogram of monthly variation of SST from 1981 to 2010.](image)

It can be seen from figure 3 that there is an obvious inter-monthly variation law of SST in the whole study area from January to December. The month with the lowest SST average is February (about 19.9℃), the highest SST is August (about 28.5℃). The remaining months are the transition months of the inter-monthly SST change process. The 12-months average temperature trend has a large “S” shape that is rotated 90 ° clockwise and stretched. From February to August, the SST rises month by month, with May, June and July rising faster; From August to February, the SST dropped month by month, among which December and January fell faster. From the difference between the maximum and minimum values, it can be seen that the north-south temperature difference in the study area is large in winter and small in summer; the difference between the maximum and minimum SST is the largest in March, about 19.1℃, and the smallest in September, about 5.6℃.

In order to explore the monthly spatial-temporal distribution characteristics of SST in the study area in the new climate reference period (1981-2010), this paper performs monthly average processing of SST data and ocean current data at various grid points from January to December. Then overlay the SST and ocean current monthly average data for different month to obtain SST and ocean current distribution map, as shown in Figure 4.
Figure 4. Distribution of SST and current in February and August in the East China Sea and adjacent waters from 1981 to 2010 (Isotherms are separated by 0.5°C; the direction of the arrow indicates the direction of the ocean current, and the length of the arrow indicates the velocity of the current; other months are omitted.).

Combined with SST and ocean current distribution and changes in the study area from January to December, it can be seen that:

February is the month with the lowest SST in the study area, August is the month with the highest SST, and the other months are transition months between the two.

The distribution pattern of SST in the study area in February (winter) is basically the same as that of the 30-year average climate distribution. In February, SST in the study area range from 6.5°C to 25.5°C, and the temperature difference is 19°C. The highest temperature is about 25.5°C, located at 21.25°N, 121.5°E, near the entrance of the Kuroshio. The lowest temperature is about 6.5°C, and it appears in the offshore of eastern Jiangsu (33.25°N, 122.75°E). On the whole, SST increases from northwest to southeast, and the sea temperature in the Kuroshio area is significantly higher than that in the continental shelf and the Northwest Pacific.

In February, the coastal current of the East China Sea[19] flows from north to south, and the sea water temperature is low. Under the influence of East China Sea coastal current, the isotherm of the continental shelf in the East China Sea, especially the coastal area, is particularly prominent to the south. A very obvious low-temperature water tongue appears in the sea area of the continental shelf of the East China Sea, north of 28.75°N and west of 126°E. The axis is around 33.25°N, 122.75°E to 28.75°N, 123°E. The isotherm at continental shelf was dense in February, and the horizontal temperature gradient was large. In February, there was a high temperature water tongue in the Kuroshio. Its axis was near 24.75°N, 123.25°E to 29.75°N, 130.75°E, and it was northeast to southwest trend. The angle between the axis and the latitude was about 45 degrees. In the Northwest Pacific region, the isotherms are banded and parallel to the latitude. There are 11 isotherms in 10 latitudes at the Kuroshio and the Northwest Pacific, and the horizontal gradient of temperature change is small.

In August (summer), SST in the study area ranged from 22.5°C to 29.5°C, with a temperature difference of 7°C. The highest temperature is about 29.5°C, occurred in the Kuroshio and the Northwest Pacific. The lowest temperature is about 22.5°C, occurred near the offshore area (33°N, 121°E) in the northwest of the study area. In the sea area near Haitan Island, there is a sub-low temperature center point, the lowest value is about 27°C. The existence of the hypothermic center is closely related to the upwelling near Haitan Island in summer. In the summer, the Taiwan warm current and the East China Sea coastal current flowing from south to north are uplifted by the terrain and form upwelling[20]. This upwelling drives the cold water from the bottom to the surface, resulting in lower SST in the affected area. Overall, SST in August increased from northwest to southeast.

In August, the influence range of warm current (including Kuroshio and Taiwan warm current) in the study area expanded to the north, the coastal current in the East China Sea transformed into warm current, flowing from the south to the north, and the influence range extended to the eastern area of the Yangtze River Estuary. In August, the isotherms in the study area are dense in the north, sparse in the
south, dense in the west and sparse in the east. The distribution of isotherms is relatively dense in the continental shelf area. The Kuroshio and the Northwest Pacific are relatively sparse, with only an isotherm at 29℃. In the coastal waters in the northwest of the study area, that is, around 33°N and 121°E, the isotherms strike a north-south trend, with 8 isotherms in 1.5 meridional distances. The isotherms are relatively dense and the horizontal gradient of temperature changes is larger. In most of the sea areas of the continental shelf, the isotherm is a strip distribution, showing a northeast-southwest trend. The isotherms in the Taiwan strait region are annular. In the Kuroshio area, the isotherm runs from northeast to southwest. In the Northwest Pacific the isotherm runs east-west.

3.3. Annual variation characteristics of SST
In order to clearly show the size of annual temperature difference and regional difference of surface water in the study area, the annual temperature difference diagram of surface water in the study area is obtained by subtracting the lowest February from the highest mean SST in August, as shown in figure 5 (left).

In general, the monthly dispersion of SST can reflect the annual variation of SST. In order to study the monthly dispersion degree of SST at each data point and its spatial distribution law, the monthly Coefficient of Variation of mean SST at each data point in the study area from January to December was calculated to represent the dispersion degree. When the monthly coefficient of variation of SST was larger (smaller), it means that the annual variation of SST is also larger (smaller). See figure 5 (right).

In the continental shelf waters, the annual temperature difference of the surface waters is between 9℃ and 19.91℃, and the annual temperature difference decreases from northwest to southeast. The isolines are relatively dense, and there are 22 isolines distributed in the whole continental shelf waters. The highest value center is near 33.25°N, 122°E (in the eastern Jiangsu waters). The contour lines in the continental shelf area between 29°N and 33.25°N show a high-value tongue distribution, and the axis position is approximately 33.25°N, 122.75°E to 29°N, 123.5°E. The contour area of the continental shelf area is dense. The reason of the annual temperature difference contour of the surface waters of the continental shelf presents a high-value lingual distribution is, in February, the coastal current of the East China Sea flows from north to south, bringing lower-temperature seawater, resulting in significantly lower SST in the coastal waters than in the offshore waters of the same latitude. In August, the coastal circulation of the East China Sea flows from south to north, and the SST near the shore is relatively uniform compared with that of the offshore sea at the same latitude, the annual temperature difference contour distribution appears a high value area.

In the Kuroshio, the annual temperature difference of the surface seawater is between 3.84-9℃, which is the smallest compared with the sea area of the same latitude, which is mainly related to the control of the Kuroshio warm current all the year round; the lowest annual temperature difference center of the surface seawater is near the entrance of the Kuroshio (21.25°N, 121.75°E), which is 3.84℃. The annual temperature difference between the surface seawater from the entrance of the
Kuroshio to the exit of the Kuroshio gradually increased. The distribution pattern of contour lines is low-value tongue-like. The axes are located near 24.75°N, 123.25°E to 29.75°N, 130.75°E, with a northeast-to-southwest trend. The angle between the axis and the latitude line is about 45 degrees.

In the Northwest Pacific, the annual SST temperature difference is between 4.5℃ and 9℃, and the annual temperature contour is east-west, parallel to the latitude distribution, and increases gradually from south to north, which is mainly related to the latitude distribution of solar radiation.

The annual temperature difference of surface water in the whole study area is related to latitude. In the same latitude area, the annual temperature difference between the surface waters of the continental shelf is the largest, the Kuroshio is the smallest, and the Northwest Pacific is between the two, but the annual temperature difference is closer to the Kuroshio.

With reference to Figure 5 (right), it can be seen that the area with the largest monthly SST coefficient of variation is located in the coastal waters of the mainland. For example, the eastern part of Jiangsu reaches 0.4, with the largest dispersion (the largest change in the year). The coefficient of variation of monthly SST in the low-latitude waters of the Northwest Pacific and the Kuroshio waters is small, at 0.1, and the dispersion is small (the year's variation is small). In general, the surface temperature of coastal waters affected by coastal currents has a large annual variation; the annual variation of SST in the seas affected by the Kuroshio in the East China Sea and low-latitude oceans is small.

In order to reflect the changes of the mean value and extreme value of the SST difference in the study area over the past 30 years, the mean value, minimum value and maximum value of the SST difference in the study area over the past 12 months were used to draw the monthly variation diagram of the temperature difference, as shown in figure 6.

Figure 6. Monthly variation of temperature difference (The abscissa is the next month minus the previous month, and the ordinate is the corresponding temperature difference. The positive value represents the temperature rise, the negative value represents the temperature drop, the mean value represents the mean temperature difference of all data points in the region, and the minimum (large) value represents the inter-monthly temperature difference of the smallest (large) data points in the region.).

On the whole, the average SST from March to August in the study area is positive, indicating that the average temperature is increasing, and the positive temperature difference between March and May is increasing, indicating that the average temperature rise is accelerating. From May to July, the average SST rose the fastest, and the average rate of the whole region was higher than 2℃/per month. The average value of SST difference from September to February of the next year is negative, indicating that the average temperature is decreasing; the negative value of temperature difference from September to January of the next year is decreasing, indicating that the average temperature is decreasing faster; the minimum negative value of temperature difference in January, indicating that the average temperature in January is decreasing fastest, indicating -2.11℃/per month. Combining the minimum and maximum curves of the monthly changes in the SST difference in the study area, it can
be seen that the SST differences at all data grid points from April to July are positive, and the SST is rising; In contrast, the SST difference from October to January of the following year was negative, and the SST was decreasing.

In order to more clearly and intuitively reflect the difference in spatial distribution of monthly SST changes in the study area, the spatial distribution diagram of monthly SST differences was obtained by subtracting the corresponding SST of the previous month from the mean SST of each month for 30 years at each grid point, as shown in Fig 7.

Figure 7. Distribution of SST differences in January and May (Other months are omitted).

Figure 7 shows that the regions in the study area with a large temperature change range from January to December in the past 30 years are all located on the continental shelf of the East China Sea.

In February, some sea areas near the entrance of the Kuroshio (22° N, 122° E) started to heat up, and the temperature rise was only about 0.1°C. In March, SST was rising in the whole study area except the northernmost part of the study area (33° N, 125° E). In April, the SST in the continental shelf, especially the inner continental shelf (the sea depth is less than 50 meters), rose faster than that in other areas.

In May, June and July, the SST in the study area increased the fastest; compared the same latitudes, the temperature increase, the continental shelf sea area was the fastest, the Northwest Pacific area was the second, and the East China Sea was the slowest. The magnitude is greater than the temperature rise in the south.

In August, the study area was basically warming up, and the temperature rise was less than May to July. At the same time, it showed a more obvious pattern of fast at north and slow at south.

The SST in the study area from September to February of the next year was mainly characterized by decline. The cooling rate, comparing the same latitude region, showed that the continental shelf sea area was the fastest, followed by the Northwest Pacific, and the Kuroshio was the slowest. The cooling rate of the high latitudes is faster than that of the low latitudes.

From October to January of the next year, the regional center with the fastest SST decline moved back and forth from the northwest side of the Yangtze River estuary to the sea area around the Yangtze River estuary, and the cooling sea area continued to expand, with the cooling rate continuously accelerating. The fastest value increased from about -3.4°C in October to about -5.7°C in January.

4. Characteristics of monthly SST variation at each characteristic point

In order to analyze the differences of SST in different climatic regions over the past 30 years, the following six typical characteristic points (see figure 2) were selected for specific analysis in different climatic regions based on the previous studies.

P1, P2, P3, P4, P5 are located at 22.25° N, 26.25° N, 28.25° N, 29.75° N, 31.25° N and 128.75° E, 126.25° E, 124.75° E, 123.75° E, 122.75° E. These 5 points are on an oblique tangent line that approximates the northwest-southeast trend. Using these points can reflect the characteristics of inter-monthly changes in SST from the Northwest Pacific to the Kuroshio to the continental shelf and the differences between the three sea areas. Among them, P1 is located in the low latitudes of the
Northwest Pacific, P2 is located in the middle of the Inlet and Outlet of the Kuroshio, P3 and P4 are located in the Continental Shelf, and P5 is in the Yangtze River Estuary and Inner Continental Shelf.

P6 is located at 32.75° N, 122.25° E. From the annual variation chart of SST in the study area (Figure 5), it can be seen that this point is located near the extreme center of the inter-monthly temperature difference. Selecting this point can reflect the inter-monthly variation of the intensity of the northern Jiangsu coastal currents.

Extract the 30-year average monthly SST data of six feature points respectively, and draw the monthly change curve of each point SST from January to December, as shown in Figure 8 (left). In order to clearly reflect the inter-monthly changes in the temperature of the six characteristic points, the 12-month SST is subtracted from the SST corresponding to the previous month to obtain the monthly variation curve of the SST of the six characteristic points, as shown in Figure 8 (right).

Figure 8. The monthly distribution of SST and temperature difference of the six feature points in 30 years (The left picture shows the inter-monthly curve of SST; the right picture shows the inter-monthly curve of SST difference).

From the Northwest Pacific area to the Kuroshio then to the continental shelf area, the SST change curves at each point show the characteristics of low temperature in winter and spring, high in summer and autumn, and the curve shape is similar to the curve of "cosine function". P3, P4, P5, and P6 are located on the continental shelf of the East China Sea. The temperature is relatively low and the inter-monthly changes are large. P1 and P2 are located in the Northwest Pacific and the central Kuroshio, respectively. At the same time, these two points have high SST and small monthly changes. The SST at each point is the lowest in February. The P1 point has the highest SST in July, and the other five points have the highest SST in August. In other words, the highest monthly SST in the low latitudes is one month earlier than the high latitudes.

As can be seen from the monthly variation curve of temperature difference, the monthly variation curve of temperature difference at the six points all presents a "parabolic" shape, and the difference of SST between the six points in May and January is the biggest. The smallest negative values of SST differences between P2 (central point of the Kuroshio) and P5 (near the Yangtze estuary) occurred in December, while the smallest negative values of SST differences between the other four points all appeared in January. The maximum positive temperature difference between P2 located in the middle of the Kuroshio and the P3 located on the outer continental shelf appeared in July, and the maximum positive temperature difference between the other four points appeared in May.

Based on the foregoing, it can be seen that the rise or fall of SST at each characteristic point is largely influenced by latitude. At the same time, the current direction and the characteristics of the current in different seasons are closely related to the change rate of SST.

5. Conclusion
This paper uses the new climate reference period (1981-2010) as the research period, and uses the global bottom depth data released by the National Geophysical Data Center in 2009, SST data and currents in the SODA-2.2.4 data set. The data are used to comprehensively analyze the climatic zoning
of SST in the East China Sea and adjacent sea areas and the climatic characteristics of each area. The following conclusions are obtained:

1) The research areas can be divided into three climatic regions: the continental shelf area, the Kuroshio in the East China Sea and the Northwest Pacific, under the influence of factors such as the distribution of land and sea shapes, latitude, and currents. The 30-year average SST in the study area was about 24.1℃, the highest was about 27.6℃, and the lowest was about 16.3℃. The SST from the continental shelf to the Kuroshio, then to the Northwest Pacific showed an overall low - high - second high trend. The distribution of isotherms is more intensive in the continental shelf area and less in the Kuroshio and the Northwest Pacific Ocean.

2) The SST in the study area was the lowest at about 19.9℃ in February and the highest at about 28.5℃ in August. Due to the influence of changes in direct sunlight, the highest month of SST in low-latitude sea areas is July, and in high-latitude sea areas is August. The month with the highest SST in low latitudes is one month earlier than in high latitudes. The isotherm in the study area was dense in February, and the temperature difference between the north and the south was large; the lowest value was about 7℃, located near the east coast of Jiangsu (33.25° N, 122° E); the highest value was about 25℃, near the Kuroshio inlet (21.25° N, 122° E); the temperature difference is around 17 ℃. The isotherms in the study area were sparse in August, and the temperature difference between the north and the south was small; the lowest temperature was about 23 ℃, which appeared in the near-shore area in the northwest of the study area. In addition, in the sea area near Haitan Island, a sub-low temperature center point exists due to the influence of upwelling. The highest SST is around 29℃, which is located in the southern part of the study area. The temperature difference between the lowest value and the highest value is about 6℃.

3) The annual temperature difference of the surface waters in the whole study area (August minus February) is related to latitude. In the same latitude area, the annual temperature difference between the continental shelf waters is the largest, the Kuroshio sea area is the smallest, and the northwest Pacific Ocean is in between, but closer to the Kuroshio sea area. According to the monthly variation coefficient of SST, the annual variation of SST decreases from northwest to southeast.

4) SST rose the fastest in May, June, and June; SST fell the fastest in December and January. For the same latitude, the rate of SST rising and decreasing is the largest in the western continental shelf sea area, the second in the eastern Northwest Pacific sea area, and the smallest in the central Kuroshio sea area. The SST rises and drops faster in the high latitude area than in the low latitude area.

Acknowledgments
The research was supported by the Scientific Research Development Foundation of Shanghai Normal University (KF201824). The research content of this paper has been guided by Chen Zhang and Fen Xu, and I would like to thank them for that.

References
[1] IPCC. (2014) Climate change 2013: the physical science basis. Cambridge: Cambridge University Press, Cambridge.
[2] UN Environment. (2012) Global Environment Outlook 5 Summary for Policymakers. http://wedocs.unep.org/bitstream/handle/20.500.11822/8057/-GEO-5%20Summary%20for%20Policy%20Makers-20121089.pdf?sequence=8&isAllowed=y.
[3] UN Environment. (2019) Global Environment Outlook 6 Summary for Policymakers. https://wedocs.unep.org/bitstream/handle/20.500.11822/27652/GEO6SPM_EN.pdf?sequenc e=1&isAllowed=y.
[4] Fang, G., Wang, Y., Wei, Z., et al. (2009) Interoccean circulation and heat and freshwater budgets of the South China Sea based on a numerical model. Dynamics of Atmospheres and Oceans, 47(1-3):0-72.
[5] Bao, X.W., Wan, X.Q., Gao, G.P., et al. (2002) Seasonal variation characteristics of AVHRR sea surface temperature field in the Bohai Sea, Yellow Sea, and East China Sea. Acta
Oceanologica Sinica, 24 (5).

[6] Feng, S.Z., Li, F.Q., Li, S.J. (1999) Introduction to Marine Science. Higher Education Press, Beijing.

[7] Su, J.L., Yuan, Y.L. (2005) Chinese offshore waters. Ocean Press, Beijing.

[8] Sun, X.P. (2006) Ocean in China's offshore areas. Ocean Press, Beijing.

[9] Wu, Z.Y., Min, J.Z., Chen, H.X., et al. (2008) Correlation between Kuroshio temperature and salinity in the East China Sea and temperature and precipitation in eastern China. Advances in Marine Science, 26 (2).

[10] Qi, Q.H. (2010) Low-frequency variation of Kuroshio heat transport in the source area and its relationship with SST anomalies in China's offshore areas. Straits of Taiwan, 29 (1): 106-113.

[11] Wu, Y.M., Xu, Z.L., Fan, W., et al. (2011) Analysis of the spatiotemporal variation of sea surface temperature in the East China Sea from 1985 to 2005. Chinese Journal of Oceanology, 33 (6): 9-18.

[12] Kang, J.C., Wang, G.D., Zhu, J., et al. (2012) Monthly variation of temperature in Kuroshio area of the East China Sea. Ocean and Lake Marsh, 43 (5): 877-883.

[13] Duan, J., Chen, C.H., Wu, L.X. (2014) Observation and analysis of intraseasonal changes of currents in the Kuroshio source area. Advances in Earth Science, 29 (4): 523-530.

[14] Yin, M., Xiao, Z.N., Li, X., et al. (2016) Evolution of Kuroshio Warm Tongue in the East China Sea and Its Impact on Air Temperature in China. Climate and Environmental Research, 21 (3): 333-345.

[15] Carton, J.A., Giese, B.S. (2008) A Reanalysis of Ocean Climate Using Simple Ocean Data Assimilation (SODA). Monthly Weather Review, 136(8):2999-3017.

[16] Ricciardulli, L., Wentz, F.J. (2015) A Scatterometer Geophysical Model Function for Climate-Quality Winds: QuikSCAT Ku-2011. Journal of Atmospheric and Oceanic Technology, 150904131243002.

[17] Wang, S.H., Zhao, Y.D., Yin, X.Q., Qiao, F.L. (2018) Research Status of Global Ocean Reanalysis Products. Advance in Earth Sciences, 33 (08): 794-807.

[18] Amante, C., Eakins, B.W. (2009) ETOPO1 1 Arc-Minute Global Relief Model: procedures, data sources and analysis. Psychologist, 16(3):20 - 25.

[19] Qiao, F.L. (2012) Regional Oceanography in China. Physical Oceanography[M]. Ocean Press, Beijing.

[20] Yan, T.Z. (1991) Preliminary Classification of Causes of Coastal Upwelling in China. Marine Bulletin, (06): 3-8.