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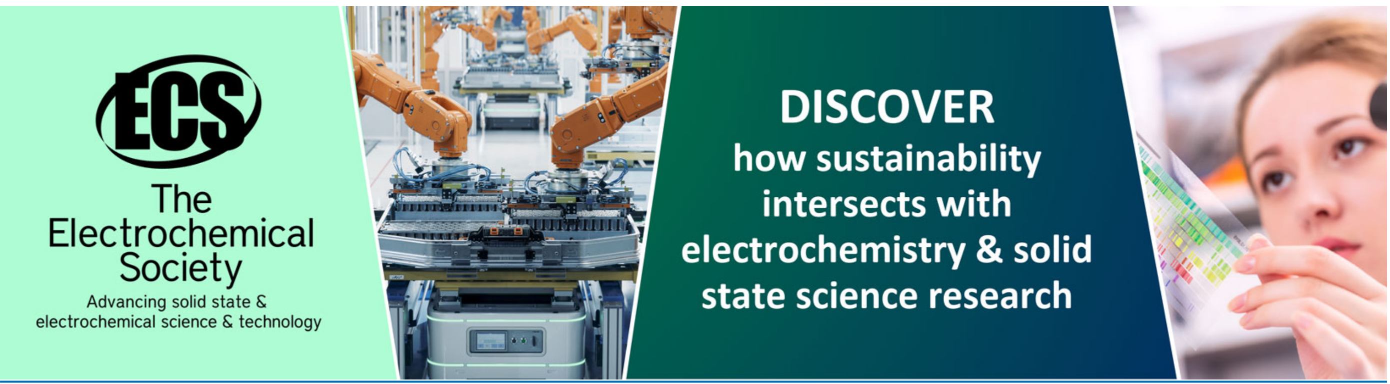


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# The Climatic Characteristics of Surface Salinity in the South China Sea and the Adjacent Northwest Pacific Ocean

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**Abstract.** Based on the high-resolution SODA oceanographic hydrological reanalysis data, analyzing the climatic characteristics of the surface salinity in the South China Sea and the adjacent Northwest Pacific Ocean during the new climatic baseline period from 1981 to 2010 in this paper. The results showed that: Sea surface salinity (SSS) in the research area could be obviously divided into two areas, the South China Sea and the Northwest Pacific Ocean. The SSS in the South China Sea was lower than that in the Northwest Pacific Ocean. The annual amplitude of SSS in the South China Sea varied in different sea areas, but it was smaller and almost same in the Northwest Pacific Ocean area. The inter-monthly variations of SSS were the same at continental shelf side and the sea area near the island in the South China Sea, however differences existed with that in the central of the South China Sea. The inter-monthly variation of SSS in the Northwest Pacific Ocean varied from low latitude to high latitude and the salinity field showed "high-low-high" distribution. According to the climatic characteristics of salinity, the research area could be divided into five climatic zones. Among them, the South China Sea was divided into areas A and B, and the Northwest Pacific Ocean was divided into areas C, D, and E. As water invading from the Northwest Pacific Ocean to the South China Sea area that caused a higher salinity in area B than in area A. The northern equatorial current influenced on the Northwest Pacific Ocean, that caused the salinity in area D lower than in areas C and E.

## 1. Introduction

Climate change posed an imminent and irreversible threat to human society and the planet (Paris Agreement, 2015). Nowadays climate change has become the most important environmental issue in our society (United Nations Global Environment Outlook 5 (GEO5), 2012).

Research on climate change has become one of the hottest issues of the international community [1, 2]. In order to meet the needs of accelerating climate change research, in 2015, the World Meteorological Organization (WMO) Commission for Climatology formally proposed to adopt the 1981-2010 period as the latest baseline for climate change.

The ocean was an important part of the climate system, which played a crucial role in the energy balance and material balance of the climate system. Marine salinity was one of the most important indicators of climate change and also an important regulator of the climate system, which had a significant impact on local and global climate change. Making researches on the structural features of ocean salinity climate was of great significance for understanding climate and explaining climate change.

The predecessors had analyzed the monthly average salinity change using the SODA dataset from 1972 to 2010 [3] and discussed the variational characteristics of salinity in the sea area and the relationship between salinity and ENSO according to the seasonal, inter-annual and even inter-decadal scales [4, 5]. However, there was a lack of a clear and systematic study of the climatic structure and

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the monthly variation of the salinity field, especially a lack of in-depth analysis of the climatic structural characteristics of new climate change baseline period.

So, in this paper, the structural features of the salinity field in the South China Sea and the adjacent Northwest Pacific Ocean over the new climatic base years analyzed mainly, and quantitatively analyzed the inter-monthly variation of the salinity structure at the surface layer, which provided a baseline for studying regional climate change and an effective reference for "understanding the past, present and future climate change process."

## 2. Research Area

In this paper, the South China Sea and the adjacent Northwest Pacific Ocean were chosen as the study area whose latitude and longitude range were 105.25-140.25°E and 0.25-25.25°N respectively, as shown in Figure 1.

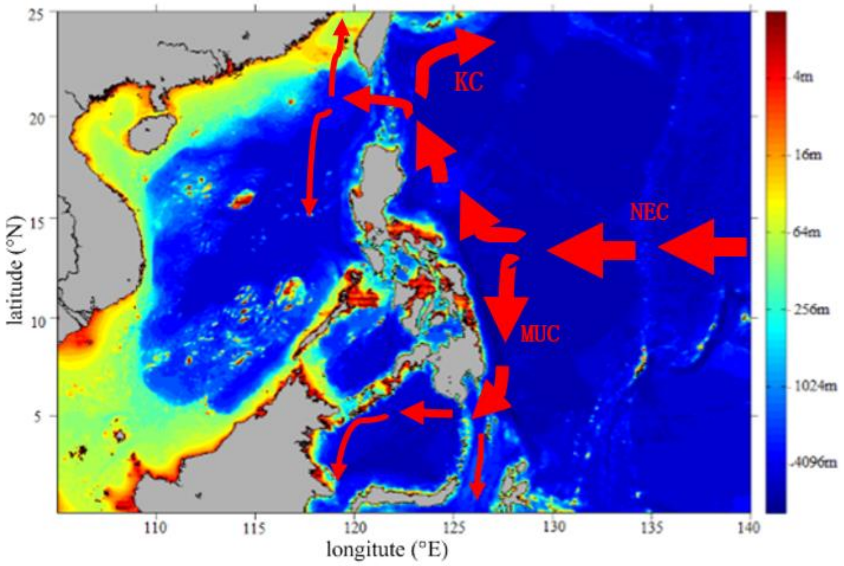


**Figure 1.** Schematic diagram of the study area (color bars represent seawater depth; red arrows represent the main currents in the area).

## 3. Data and Methods

### *3.1. Salinity Data*

Simple Ocean Data Assimilation (SODA_2.2.4 monthly average data) quoted in this paper was a reanalysis product and collected by Global Simple Ocean Data Assimilation System which was derived from the University of Maryland and Texas A & M University. The time span was from January 1871 to December 2010 and the horizontal grid was 0.5° × 0.5° and salinity data was vertically divided into 40 layers of unequal spacing. The dataset included seven variables such as temperature, salinity, latitudinal current velocity, Longitude current velocity, zonal sea surface wind stress, longitude surface wind stress and sea surface height.

### *3.2. Topographic Data*

Topographic data were derived from the 1-Minute Gridded Global Relief Data (ETOPO1) released by the National Geophysical Data Center (NGDC) of US in 2009. The grid of the database was 1'x 1', and the depth of the grid was 1 m [6].

### *3.3. Analytical Methods*

- Surface data was extracted from the latest climate baseline period (January 1981- December 2010). In the study area, annual variation of surface salinity and the monthly salinity in climatic distribution chart at surface layer were drawn to quantitatively analyze the variational characteristics of salinity field.

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- The annual amplitude of surface salinity was calculated by extracting the maximum and minimum values of surface salinity from January to December in the latest climatic baseline period for each point in the study area. The annual amplitude map could intuitively reflect the variation range of salinity in different sea areas and explore the spatial distribution of salinity in each area in detail.

## 4. Results Analysis

### *4.1. The Climatic Distribution of Salinity at Surface*

Using the surface salinity information of SODA dataset, it could be drawn the climatic structure chart of surface salinity and surface salinity annual amplitude map for the study area, respectively were shown in Figure 2, with the isohaline space 0.25psu.

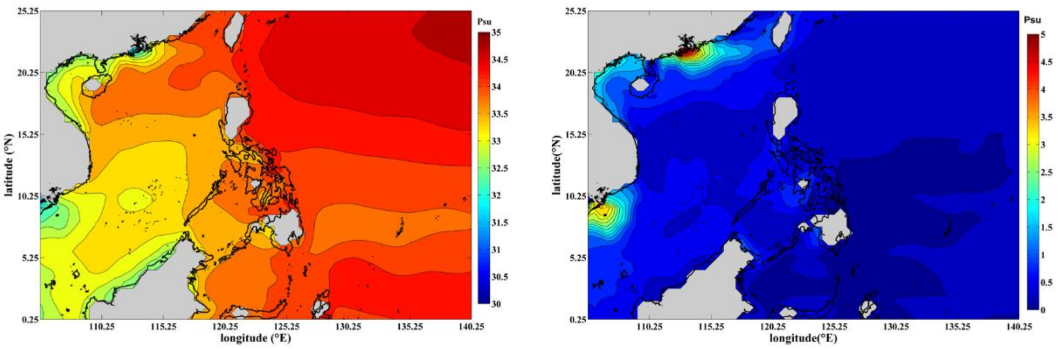


**Figure 2.** The climatic status map of surface salinity in the study area (left); Yearly variation of surface salinity in the study area (right).

Figure 2 (left) showed the climatic structure of surface salinity in the study area. It could be seen from the figure, salinity ranged from 31.5 to 34psu in the South China Sea. Salinity distributed on the one side of the continental shelf and near the island showed a lower value, with a higher value in the northeast sea area which presented a downward trend from the northeast to the southwest. The SSS values in the central South China Sea gradually decreased from high latitude to low latitude and ranged from 33.2 to 34psu. The isohaline presented a belt distribution feature. Among them, there was a low-salinity nucleus with 33.25psu near the southeast location (112.75 °E, 10.25 °N). It could be seen that the salinity of the sea areas to a great extend affected by the river runoff was low and the isohalines are dense. In the central sea area, the salinity was relatively high and the isohalines are sparse.

In the Northwest Pacific Ocean, surface isohaline generally presented a belt distribution feature along the latitudinal direction and closed off near the coast of the Philippines. From low latitude to high latitude, the salinity field showed a "high-low-high" distribution characteristics. Low-salinity nuclei occurred near the 7.75 °N cross section in the central Northwest Pacific Ocean at about 34psu.Salinity was between 34-34.85psu in the north of the low-salinity nuclei area and 34-34.5psu in the south of the low-salinity nuclei area.

Figure 2 (right) was the surface salinity’s annual amplitude in the study area. As seen in the figure, in the South China Sea, salinity’s annual amplitude varied in different sea areas. The maximum amplitude appeared in the vicinities of Hong Kong and Macao, reaching as high as 4.66psu, followed by the northern Gulf of Thailand and the Beibu Gulf with a variation of 1.5-3.5psu, all appeared around the estuary of the rivers. The minimum annual amplitude of salinity appeared in the middle of the South China Sea at about 0.5psu.

In the Northwest Pacific Ocean, the annual amplitude of salinity was less than 0.5psu and whose distribution was uniform. In the north area of 15 °N, the annual amplitude of salinity was about 0.25psu. In the southwestern part of 15 °N, the minimum annual amplitude of salinity was 0.08psu.

In contrast, the sea area with large annual amplitude was distributed on the continental shelf side, especially near the estuaries largely affected by the river runoff, indicating that the annual amplitude of salinity was mainly related to the inflow of the river runoff.

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*4.2. Monthly Variation Characteristic of the Surface Salinity*

There were 3 regions for South China Sea as the north of 20 °N, between 10-20 °N and south of 10 °N, and similarly 3 regions for Northwest Pacific Ocean as the north of 15 °N, between 5-15 °N and south of 5 °N. As shown in Figure 3.

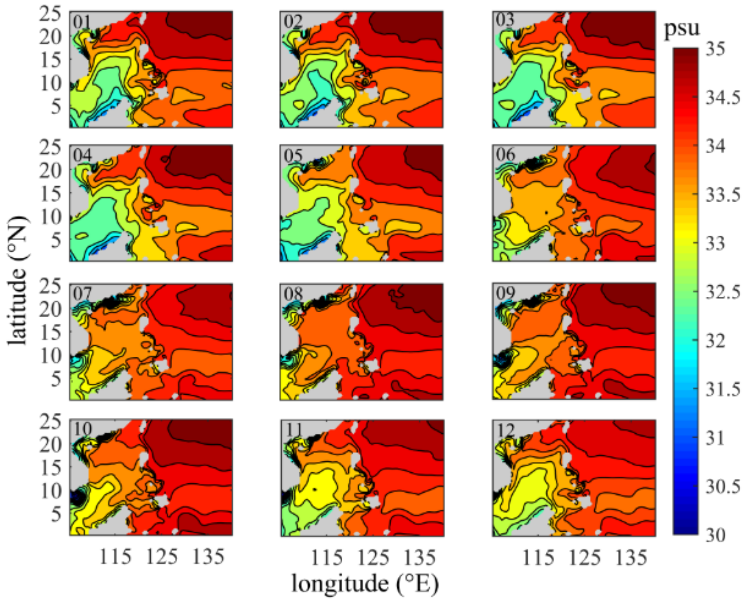


**Figure 3.** Monthly climatic status map of surface salinity in the study area (color bar indicates salinity range).

- In the north of 20 °N for South China Sea, the isohaline had a belt and more dense distribution feature. From January to April, the salinity was constant. The salinity of Beibu Gulf was lower than that of northeastern South China Sea, and the SSS gradually decreased from May to September. The salinity near Hong Kong and Macao sea areas dropped significantly, reaching the lowest in September with 30psu and SSS rose slowly from October.
- Between 10 °N and 20 °N of South China Sea, SSS decreased from high latitude to low latitude. From January to May, the salinity was constant. From June to August, the SSS increased and distributed in a clumpy structure, which could extend to the Mindoro Strait with around 34psu. From September, the SSS with clumpy structure decreased and gradually presented the belt distribution features again in October.
- In the south of 10 °N for South China Sea, salinity was constant from January to May and gradually increased from June to September. However, the salinity in the northern Gulf of Thailand decreased obviously and the low-salinity nuclei continued to expand outward which reached a minimum value of about 30psu in October. From then, the SSS gradually decreased and the salinity in northern Gulf of Thailand increased. It could be concluded that the inter-monthly variation of salinity in the northern Gulf of Thailand was mainly related to the runoff.

In the north of 15 °N for Northwest Pacific Ocean, SSS was generally high, above 34.5psu. From January to April, the high-saltwater tongue intruded into the South China Sea from the Northwest Pacific Ocean via the Luzon Strait, reaching a maximum of 111.5 °E, which was very similar to the simulation results of the predecessors [7]. In May, high-saltwater tongue disappeared and returned to the east of 121 °E near the Northwest Pacific Ocean in September, during which was the involution phase period. In October, high-saltwater tongue reappeared. In November, high-saltwater tongue strongly moved to the west of the South China Sea, reaching about 113 °E.

- Between 5 °N and 15 °N of Northwest Pacific Ocean, the isohaline presented a belt distribution feature along the latitude. From January to May, the salinity was constant and gradually increased from June to October. The salinity began to decrease in November.

- In the south of 5 °N for Northwest Pacific Ocean, the isohaline extended westward presenting a belt distribution feature. From January to March, salinity remained unchanged. From April to October salinity was relatively high and then decreased slowly from November.

*4.3. The Climatic Zones of Salinity Distribution*

According to the climatic states of surface salinity distribution, the climatic state characteristics of monthly surface salinity distribution, and the terrain, ocean currents, and other factors in the research area, the area could be divided into five small climatic regions (Figure 4). Among them, the South China Sea and the Northwest Pacific Ocean was bounded by 121.25 °E, the South China Sea was bounded by 16.75 °N, and the Northwest Pacific Ocean were bounded by 4.75 °N and 14.75 °N. They are:

Area A (South of the South China Sea): 105.25-121.25 °E, 0.25-16.75 °N;
Area B (North of the South China Sea): 105.25-121.25 °E, 16.75-25.25 °N;
Area C (South of the Northwest Pacific Ocean): 121.25-140.25 °E, 0.25-4.75 °N;
Area D (Central of the Northwest Pacific Ocean): 121.25-140.25 °E, 4.75-14.75 °N;
Area E (North of the Northwest Pacific Ocean): 121.25-140.25 °E, 14.75-25.25 °N.

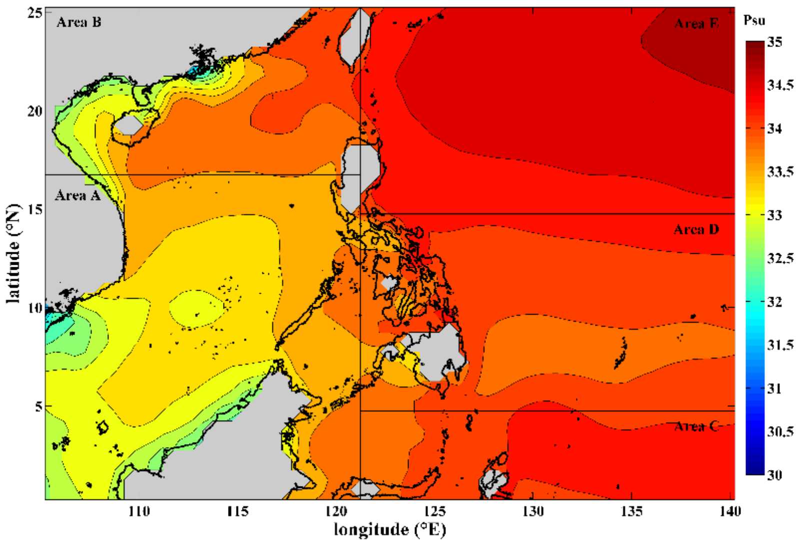


**Figure 4.** The climatic zones of surface salinity diagram (solid line showed zoning boundary).

From the figure 4 showed that the divisions of areas A and B mainly reflect the influence of the Northwest Pacific Ocean on the South China Sea through the Luzon Strait. Finally, area B was the affected area, and area A was basically not affected by it. The salinity of area B was higher because of the influence of the Northwest Pacific Ocean currents on Area B, and the closer to the Luzon Strait, the higher the salinity; whereas, the salinity of Area A was relatively low due to the influence of precipitation and coastal runoff.

The differences in salinity between the C, D and E areas in the Northwest Pacific Ocean mainly reflected the effects of the Northern Equatorial Current. The salinity of Area D that was the mainstream area of the Northern Equatorial Current was lower than that in areas C and E. The low-salt nucleus appears in the middle of area D and was closed.

## 5. Conclusion

Using SODA ocean hydrothermal reanalysis data, the climatic state characteristics of surface salinity in the South China Sea and the adjacent Northwest Pacific Ocean were analyzed in this paper. The following conclusions could be drawn:

(1) The salinity field in the study area could be divided into two areas, the South China Sea and the Northwest Pacific Ocean. The SSS in the South China Sea was significantly lower than that of the SSS

in the Northwest Pacific Ocean. The salinity showed a decreasing trend from the northeastern Northwest Pacific Ocean to the southwestern South China Sea. In the South China Sea, annual amplitude of SSS varied in different sea areas. The maximum amplitude appeared at 4.66psu in the area near Hong Kong and Macau on the continental shelf side and the minimum one appeared in the central part of the South China Sea at about 0.5psu. The SSS annual amplitude in the Northwest Pacific Ocean was smaller and even generally consistent, and the minimum value appeared in the southwest at 0.08psu.

(2) In the South China Sea, SSS low value areas were mainly distributed on the continental shelf side, Hong Kong, Maucao, Beibu Gulf and northern Gulf of Thailand, which was between 31.5-33psu with obvious periodic variation. From January to April, salinity increased. From May to October, salinity decreased. From November to December, salinity increased. And isohaline presented belt distribution features. The salinity in central South China Sea from January to May remained basically unchanged with a belt distribution feature. From June to September, salinity increased and showed a clumpy distribution feature. From October to December, salinity decreased and isohaline restored to belt distribution features. The distribution of SSS in the Northwest Pacific Ocean from low latitude to high latitude showed a “high-low-high” trend and isohaline presented belt distribution features. In the south of 4.75 °N and in the north of 14.75 °N, high salinity area (34.2-35psu) existed. While the area between the north of 4.75 °N and the south of 14.75 °N was the low salinity areas (33.95-34.4psu).

(3) According to the climatic structure of surface salinity in the study area, the area could be divided into five small climatic zones. In the South China Sea, the salinity characteristics of Kuroshio that originated in the northwestern Pacific Ocean and invaded the South China Sea through the Luzon Strait was different because of the influence of the northwest Pacific. Among them, the influence of the B zone was relatively large, resulted in the salinity in area B was higher than that in area A. In the Northwest Pacific Ocean, the salinity of the D zone that influenced by the Northern Equatorial Current was lower than that of the C zone and the E zone.

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