Mechanisms of Salinity Anomalies in the Bohai Sea in January 2007

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Abstract

In view of the fact that the practical salinity of the Bohai Sea in January 2007 was significantly higher than the multi-year mean with its horizontal distribution opposite to the latter, the factors that affect the interannual variation of practical salinity in the Bohai Sea are quantitatively analyzed based on the in-situ hydrological measurements, the annual runoff data of the Yellow River into the sea, as well as the precipitation and evaporation reanalysis data of EAR5. The results show that the local freshwater supply not only dominates the magnitude of salinity change in the Bohai Sea, but also causes the salinity in the central Bohai Sea is higher than that in the Bohai Strait in winter in some years which is in inverse to the climatological salinity field. The seesaw distribution characteristics of the freshwater supply of the Bohai, Yellow and East China Seas also strengthen the characteristics that the salinity horizontal distribution opposite to the climatological in the Bohai Sea in some years. Available observations also show that the nutrient and inorganic carbon of the Bohai Sea are much higher than that of the open ocean, which gives a rise of 0.02 ~0.2 g·kg-1 in Absolute Salinity. Therefore, it is necessary to replace the Practical Salinity with the Absolute Salinity for the accurately salinity changes study in the Bohai Sea.

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Mechanisms of Salinity Anomalies in the Bohai Sea in January 2007

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Key Points:

- The local freshwater supply dominates the salinity change of the Bohai Sea.
- The freshwater supply in the Bohai, Yellow and East Seas is characterized by a seesaw distribution, which strengthes the anti-phase distribution of Bohai Sea.
- The relative composition of the Bohai Seawater is different from the open ocean which has an impact on salinity changes.

Abstract

In view of the fact that the practical salinity of the Bohai Sea in January 2007 was significantly higher than the multi-year mean with its horizontal distribution opposite to the latter, the factors that affect the interannual variation of practical salinity in the Bohai Sea are quantitatively analyzed based on the in-situ hydrological measurements over 35 years, the annual runoff data of the Yellow River into the sea, as well as the precipitation and evaporation reanalysis data of EAR5. The results show that the local freshwater supply not only dominates the magnitude of salinity change in the Bohai Sea, but also causes the salinity in the central Bohai Sea is higher than that in the Bohai Strait in winter in some years which is in inverse to the climatological salinity field. The seesaw distribution characteristics of the freshwater supply of the Bohai, Yellow and East China Seas also strengthen the characteristics that the salinity horizontal distribution opposite to the climatological in the Bohai Sea in some years. Available observations also show that the nutrient and inorganic carbon of the Bohai Sea are much higher than that of the open ocean, which gives a rise of 0.02 ~0.2 $g \cdot kg^{-1}$ in Absolute Salinity. Therefore, it is necessary to replace the Practical Salinity with the Absolute Salinity for the accurately salinity changes study in the Bohai Sea.

Plain Language Summary

Based on a large amount of in-situ hydrographic measurements and reanalysis data, this paper reveals the mechanism of that the practical salinity of the Bohai Sea in January 2007 was not only significantly higher than the multi-year mean, but also the horizontal distribution was opposite to the latter, as well as indicates it is necessary to replace the Practical Salinity with the Absolute Salinity for accurately study of salinity changes of the Bohai Seawater.

1 Introduction

The Bohai Sea is the largest inland sea in China, surrounded by land on three sides and connected to the Yellow Sea only through the Bohai Strait, which is only 105 km wide in the southeast, and is a typical semi-enclosed bay with a small mouth and a large belly. The central basin of the Bohai Sea, facing the Bohai Strait directly, is surrounded by three shallow terrace-type bays, Liaodong Bay in the northeast, Bohai Bay in the west and Laizhou Bay in the south. The average depth of the Bohai Sea is only 18 meters, the deepest depth is 86 meters, located in the northern end of the Bohai Strait in the Old Tieshan waterway. Because of the shallow water and strong confinement, the Bohai Sea is significantly influenced by the continental climate; coupled with the influence of river runoff injected into it, the temperature and salt distribution and other hydrological characteristics of the Bohai Sea are relatively isolated and variable.

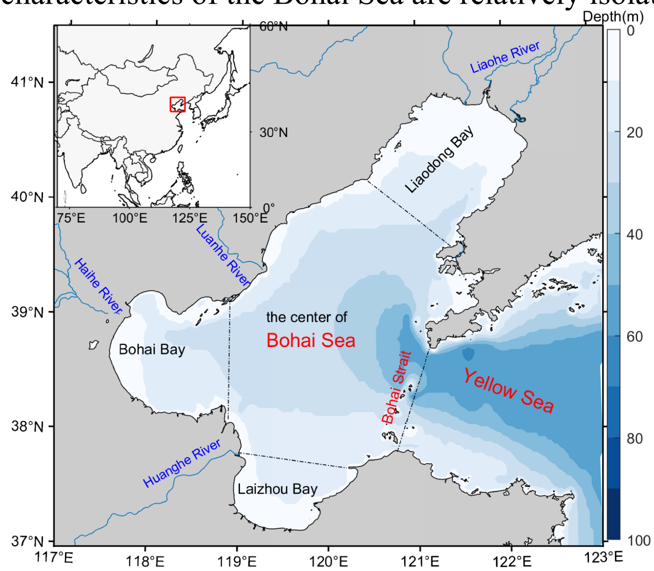

Figure 1. The Bathymetry of the Central Bohai Sea, data from Etopo 2

It's found that the salinity of the Bohai Sea in January 2007 acquired from a special project entitled Marine Integrated Investigation and Evaluation Project of China Offshore conducted from 2006 to 2007 (hereafter referred to as the '06's Investigation') is not only larger than multi-year averaged winter salinity(Chen, 1992; SOA, 2016; Zweng et al, 2019) , but also the horizontal distribution was opposite to the latter: the climate atlas shows that the salinity of Bohai Sea decreases from the eastern Bohai Strait mouth gate to the north, west and south, whereas the salinity inside the Bohai Sea is significantly higher than that in the Bohai Strait in January 2007, with the maximum value occurring along the northwest coast, and then gradually decreasing towards the eastern Bohai Strait mouth gate.

Salinity is a term used to quantify the total mass of inorganic substance dissolved in pure water to form a given mass of seawater which is as a conserved seawater property (IOC et al, 2010), now classified as an 'Essential Climate Variable' (GCOS, 2010). Local long-term trends in salinity are precisely measurable indicators for climatic changes in the terrestrial water cycle and its sensitivity to global warming (Pawlowicz et al, 2016). Such a significant change has attracted many oceanographers to conduct related research.

Based on observations of the fixed stations along the coast of Bohai Sea and the section in the central of the Bohai Sea, it was found that the salinity of seawater in the Bohai Sea has been increasing continuously since 1960, and the reasons for this are the sharp decrease in the runoff of the Yellow River, the change in the intensity of the invasion of the Yellow Sea Warm Current, and the influence of precipitation and evaporation (Lin et al., 2001; Fang et al. ,2002; Wu et al.， 2004a, 2004b; Zu et al, 2005; Xu et al, 2007; Ma et al., 2006, 2010; Jia et al., 2008);

Based on the results of the interannual statistical analysis of the salinity data of the Bohai Sea from 1950 to 1990 based on field observations, it is not only found that the salinity of the whole Bohai Sea is increasing, but also the salinity horizontal distribution of the Bohai Sea has changed fundamentally since the 1980s, and Bohai Bay has become the high value area of the Bohai Sea salinity (Yu et al., 2015); based on quasi-synoptic special investigation data, it was also found that the salinity in the Bohai Sea was significantly higher in summer 2000 and 2008 than that in summer 1958 (Wu et al, 2004b; Song et al., 2009).

The above studies obtained the magnitude and rate of salinity increase in the Bohai Sea over past decades by linear fitting, and the causes of this phenomenon by correlation analysis, but did not quantitatively analyze the changing patterns and influencing factors of Bohai Sea salinity on an annual scale; moreover, they did not explain the higher salinity in the central of Bohai Sea than in the Bohai Strait in January 2007 which is inversed to the climatological atlas. In this paper, we firstly use the in-situ observations, including quasi-synchronous field investigation, 23 years of repeat hydrographic measurements along the section B in the central Bohai Sea and the section Y crossing the Bohai Strait, and the runoff data of the Yellow River into the sea, and precipitation and evaporation reanalysis data of EAR5 to quantitatively calculate the influences of annual freshwater budget on the salinity in the Bohai Sea. Due to the poor water exchange between the Bohai Sea and the open sea, the local freshwater budget not only dominate the salinity magnitude and distribution, but also lead to the seawater nutrient and inorganic carbon significantly higher than the open ocean, resulting in the Absolute Salinity will increase by 0.02 ~0.2 $g{\cdot}kg^{-1}$, which cannot be ignored in the salinity study. Therefore, in order to accurately study the salinity variation in the Bohai Sea, Absolute Salinity should be used instead of Practical Salinity.

2 data

2.1 ‘06’s Investigation’ data

The winter salinity observation in the Bohai Sea area was from December 28, 2006 to January 23, 2007, obtained by the CTD produced by Alec Company of Japan (Xiong, 2012). The seawater salinity was calculated by temperature, conductivity, Pressure by EOS-80, the stations location is shown in Fig.2.

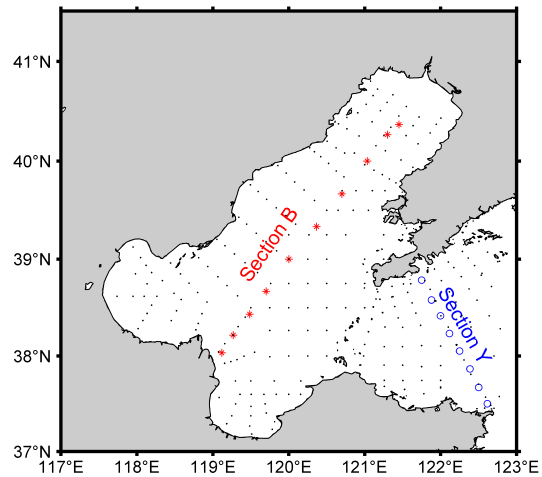

Figure 1. The location of the observations of ' 06's Investigation(.)', Section B(*) and 'Section Y (°)

2.2 Repeat hydrographic measurements along sections in the Bohai Sea over 35 years

The station locations and observation time of the repeat hydrographic measurements along sections in the Bohai Sea have stabilized since 1986. Section B, which runs through the central Bohai Sea, and Section Y, which crosses the Bohai Strait, with station locations shown in Fig. 2, basically are ensured to be investigated twice a year, with winter and summer observations made in February and August each year.

The data of sections in the winter of 1996 and 1999 when no observations were carried, are derived by linear interpolation based on the data of the two years before and after. The observation of the missing stations in 1987, 1988, 1998, 2001 and 2002, are obtained by linear interpolation of the data of the same level of the adjacent stations. Thus, a continuous series of the measurements along the section at fixed stations and fixed observation levels is formed, which ensures the reliability and comparability of the average salinity of the section.

2.3 ERA5 data

ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate covering the period from January 1950 to present. ERA5 is produced by the Copernicus Climate Change Service (C3S) at ECMWF which could be download: https://cds.climate.copernicus.eu.

2.4 Runoff data of the Yellow River into the Bohai Sea

The runoff data of the Yellow River into the Bohai Sea from 1998 to 2020 comes from the Yellow River Water Resources Bulletin released by Yellow River Conservancy Commission of Ministry of Water Resource(hereafter referred to as YRCC/MWR), which can be downloaded: www. yrcc.gov.cn/zwzc/gzgb/gb/szygb.

3 Salinity field in the Bohai Sea

3.1 Climatological salinity field in the Bohai Sea

The multi-year averaged salinity field in the Bohai Sea is analyzed based on the China Offshore Marine Atlas (Chen, 1992; SOA, 2016; Zweng et al, 2019), as shown in Fig. 3.

In winter, under the combined effect of prevailing strong northerly monsoon and sea surface cooling, the vertical convection and eddy mixing of seawater is very strong, and the spatial distribution of salinity of the water mass under the surface is basically the same as that of the surface in the Bohai Sea. In winter, the SSS (sea surface salinity) in the Bohai Sea has a strong continuity, and a salinity tongue as high as 31.5 from the northern Yellow Sea through the northern part of the Bohai Strait to the center of the Bohai Sea, so that the salinity decreases from the center to the north, west and south in three directions.

In summer, the south wind prevails in the Bohai Sea, precipitation is concentrated and reaches the maximum in a year, river runoff into the sea is the largest, the SSS drops to the lowest throughout the year, and SSS decreases horizontally from the central Bohai Strait to the north, west and south in three directions, the lowest in the top of the three bays, as shown in Fig. 3 c. Due to the smaller wind speed and the strongest solar radiation in summer, the sea surface warms up rapidly, seawater stability increases, eddy mixing becomes more difficult, and seawater salinity stratification is obvious. The salinity tends to increase below the sea surface. In the 20 m depth, the central of the Bohai Sea is mostly controlled by saltier water above 30.5, as shown in Fig.3 d.

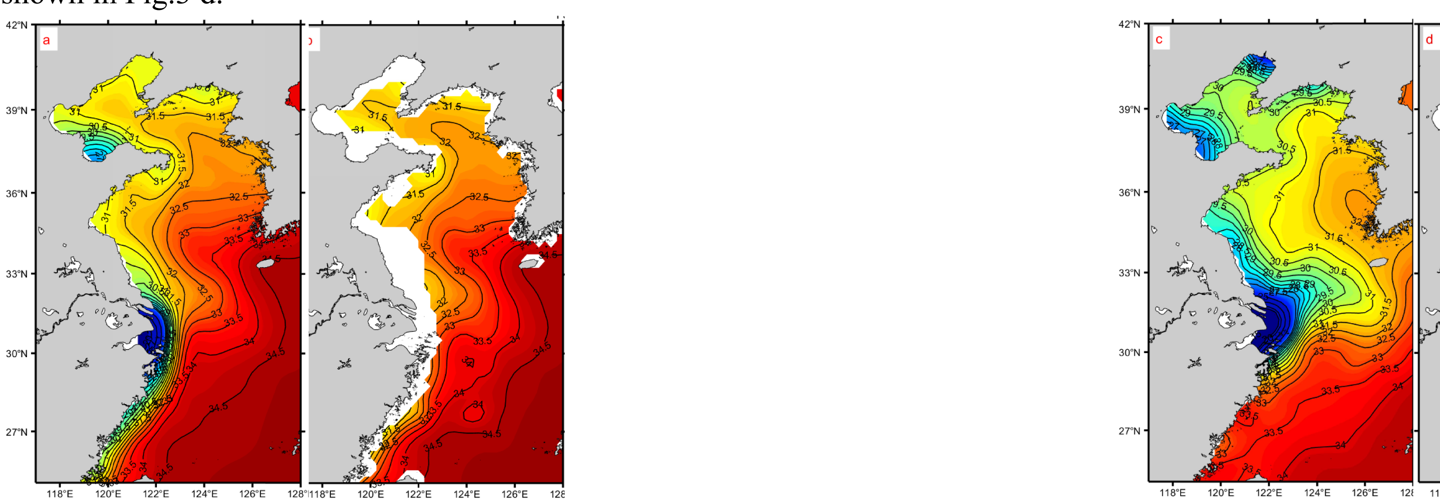

Figure 2. Salinity isoclines at (a)sea surface in winter (b) 20 m depth in winter (c) sea surface in summer (d) 20 m depth in summer

3.2 Salinity field in the Bohai Sea in winter 2007

Based on the observation of the '06’s Investigation’, the salinity isolines on different depths in the Bohai Sea in winter 2007 are shown in Fig. 4.

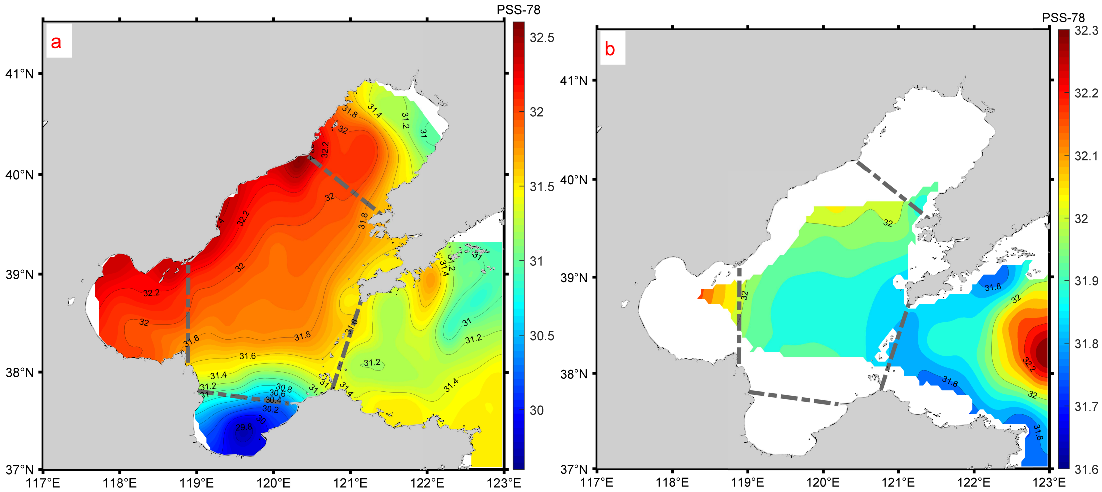

Figure 3. The winter salinity isoclines at (a)sea surface (b) 20 m depth of the Bohai Sea in '06's Investigation'

In winter, the highest SSS of the Bohai Sea, up to 32.45, is along the northwest coast, and the lowest, as low as 30.6, is in the southeast near Laizhou Bay due to its proximity to the mouth of the Yellow River. The saltier tongue can be divided into three parts, the northwest end near the coast has the most drastic change in salinity, from 32.6 to 31.9. while the salt variation in the center of the Bohai Central Sea is very smooth, ranging from 31.8 to 31.9, while at the mouth of the Bohai Strait the change is stronger, from 31.8 to 31.4 as shown in Fig.4 a.

The salinity at 20 m in the Bohai Sea does not vary much, ranging from 31.9 to 32, and is still higher in the northwest than in the Bohai Strait, which is in the southeast, like the SSS distribution.

3.3 Time series of averaged salinity of section B and section Y

As shown in Fig. 5, obvious seasonal salinity variations both appear in section B and Y during the existing 35-year observation serials. The mean salinity of summer section is significantly lower than that of winter section in the same year; the seasonal and annual variations of salinity of section B are significantly higher than that of section Y; excluding August 2001 to August 2006, winter 2018 and winter 2019, the salinity of section Y is higher than that of section B in the remaining 28 years. The salinity of section B started to be higher than that of section Y in August 2001, and then increased continuously, reaching a maximum value of 33.5 in 2003, which was 1.6 above the average salinity of section Y. The salinity of section B then decreased rapidly and was already significantly lower than that of section Y in February 2007, and continued until 2017. Subsequently, the phenomenon of inverse salinity distribution occurred again in 2018 and 2019.

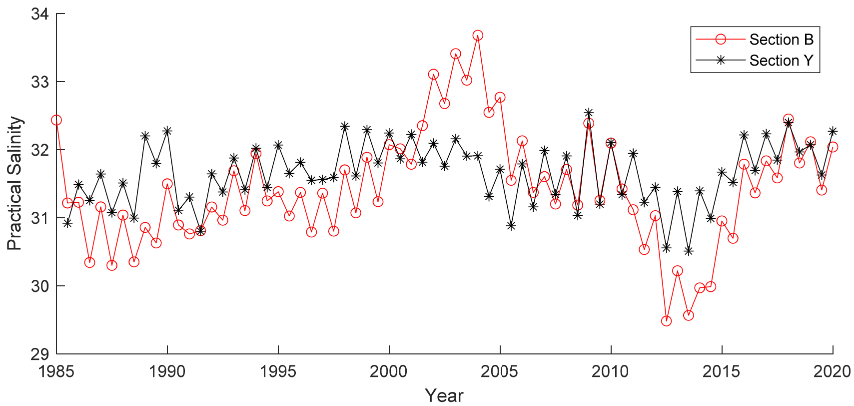

Figure 4. The average salinity of section B (red o) and Y (black *) from 1985 to 2020

Since the winter investigation period of '06's Investigation' was conducted in the Bohai Sea from December 2006 to January 2007, which was located between the summer 2006 and winter 2007 observations of the section, it can be seen in the Fig.6 and Fig.7 that the salinity of section B in August 2006 was significantly higher than that of section Y, but by February 2007, the average salinity of section B was already slightly lower than that of section Y. Although the ocean dynamics processes occurring in between are not clear, it still indicates that the '06's Investigation' is consistent with the phenomena reflected by the cross-sectional observations.

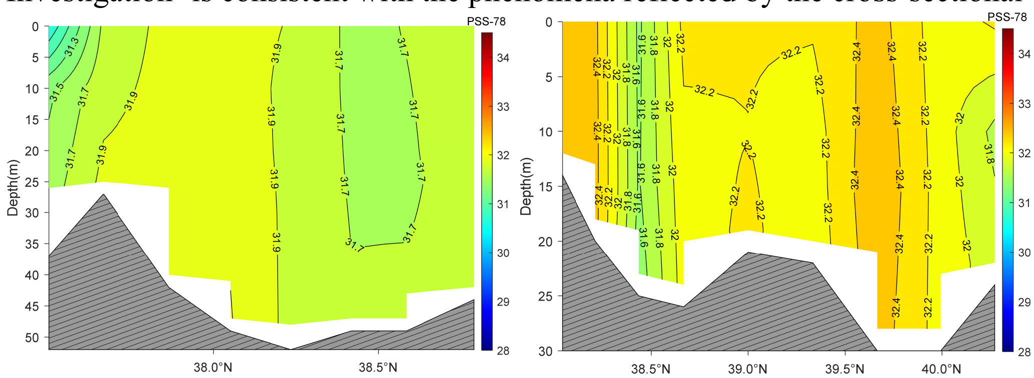

Figure 5. Salinity isoclines of section B (left) and section Y (right) in August 2006

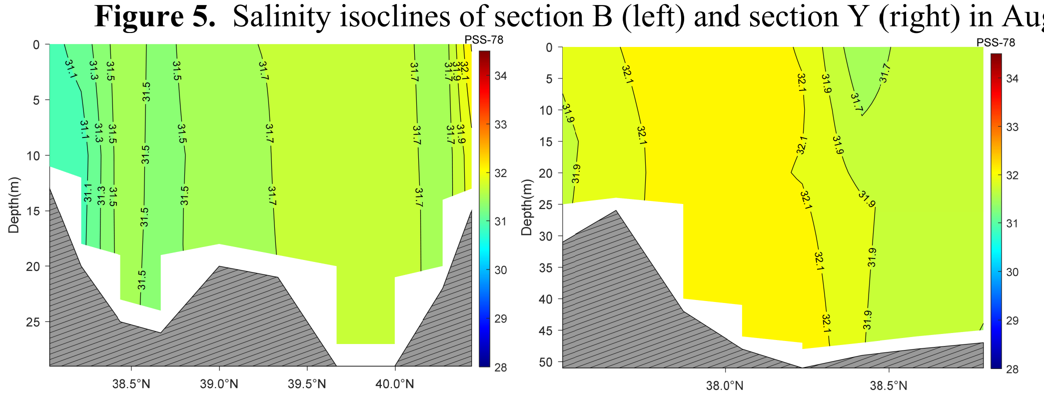

Figure 6. Salinity isoclines of section B (left) and section Y (right) in February 2007

4 Mechanisms of salinity anomalies in the Bohai Sea in winter 2007

According section 3, in most cases, the salinity in the Bohai Sea in winter is usually lower than that in the Bohai Strait, but in some years this distribution is reversed. As a measure of dissolved substances in seawater, the variation of salinity in the Bohai Sea is the result of local freshwater supplies, the replenishment of external seawater and the ionic substance input. Therefore, this section will begin with above factors.

4.1 Local freshwater budget of the Bohai Sea

The total area of the Bohai Sea is $7.73\times10^{10}m^2$, with an average depth of 18 m and a total storage capacity of $1.39\times10^{12}m^3$.

There are many rivers discharge into the Bohai Sea along the coast, but the runoff is much smaller than that of the Yellow River. Due to the climate change and human activities, the runoff discharging into the Bohai sea of the Yellow River which can be basically expressed by the measurements of its most downstream Lijin hydrological station vary significantly, as shown in Fig.8, with an average annual runoff $3.1319\times10^{10}m^3\cdot a^{-1}$ from 1956 to 2000, and $1.39\times10^{10}m^3\cdot a^{-1}$ from 1987 to 2000 (YRCC/MWR, 2020).

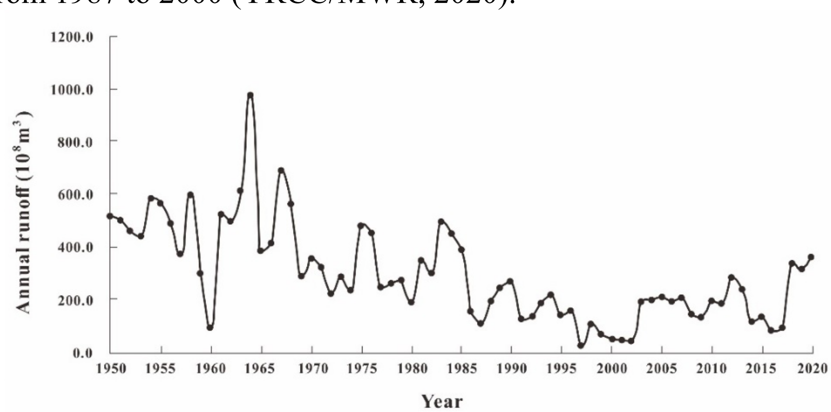

Figure 7. The annual runoff of the Yellow River from 1950 to 2020 of Lijin Hydrological Station

Due to the lack of in-situ measurement series with wide coverage and long-time span, the precipitation data of ERA5 in the Bohai Sea are evaluated with the present limited measurement of stations along the coast firstly. The multi-year averaged annual precipitation in the Bohai Sea from 1960 to 2018 is 536 $mm\cdot kg^{-1}\cdot a^{-1}$ based on the measurements of coastal stations (Fan et al, 2021) and is 710.27 $mm\cdot kg^{-1}\cdot a^{-1}$ according to the ERA5 whose distribution is higher in the central of the Bohai Sea than along the coast, shown in Fig. 9 (left). All above indicates that the ERA5 precipitation data in the Bohai Sea makes no difference with the measurements on the climatic scale and can be applied in the analysis.

The multi-year averaged annual evaporation of ERA5 is about 1170.92 $mm\cdot kg^{-1}\cdot a^{-1}$ from 1960 to 2018, which is 1.65 times the multi-year averaged annual precipitation, with high values in the central and northern Bohai Sea as shown in Fig. 9 (right), which indicates that the Bohai Sea, located in the mid-latitude monsoon region, has a dry climate.

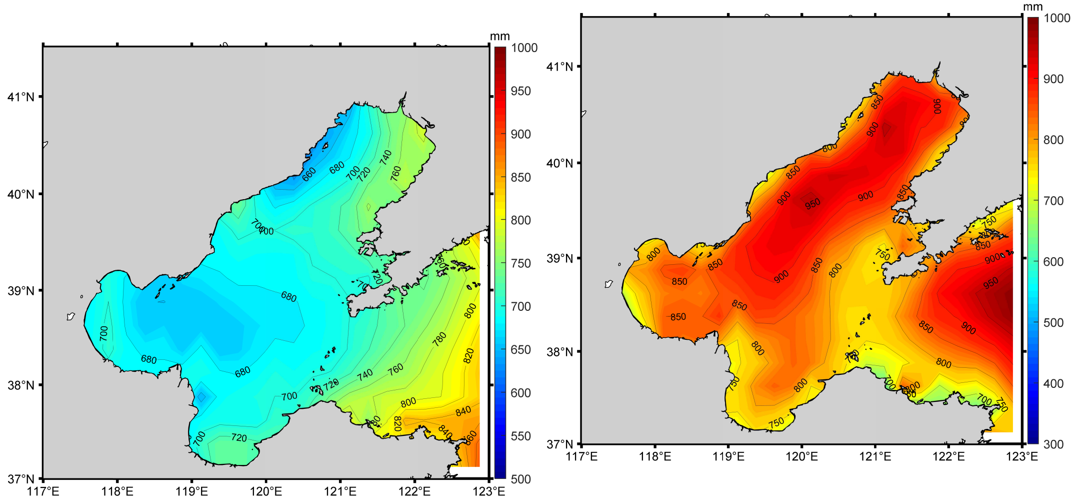

Figure 8. The isolines of multi-year averaged annual precipitation (left) and evaporation (right) of EAR 5 from 1960 to 2018

Ignoring the weak water exchange of Bohai Sea with the open sea first, the multi-year averaged annual freshwater budget (the sum of precipitation and runoff minus evaporation) is 2 orders of magnitude smaller than the total water storage in the Bohai Sea due to the annual runoff of the Yellow River into the Bohai Sea of $2.72\times10^{10}m^3\cdot a^{-1}$, the annual evaporation of $9.0\times10^{10}m^3\cdot a^{-1}$ and the annual precipitation of $5.5\times10^{10}m^3\cdot a^{-1}$ from 1959 to 2020. The following approximate formula is used to calculate the annual change in salinity of the Bohai Sea due to freshwater budget according to the salinity definition,

$$\Delta Psal_i = Psal_i \times WaterStorage/(freshWaterBudget_i + WaterStorage) - Psal_i \qquad (1)$$

In the above formula, ΔPsali is the salinity increment of the i+1th year relative to the ith year due to the freshwater budget, Psali is the average salinity of the Bohai Sea in the ith year, replaced by the mean salinity of section B in winter of the ith year, freshWaterBudgeti is the fresh water supply of the Bohai Sea in the ith year, which is the annual runoff of the Yellow River, represented by YellowRiver_Runoffi, and the annual precipitation denoted Bohai_Precipationi minus the annual evaporation of the Bohai Sea, denoted Bohai_Evapourationi in the Bohai Sea in the ith year, that is,

$$freshWaterBudget_i = YellowRiver\_Runoff_i + Bohai\_Precipation_i - Bohai\_Evapouration_i \qquad (2)$$

Since only the annual runoff of the Yellow River after 1998 is released, only the correlation between the mean salinity of Section B in winter and the predicted salinity values based on the freshwater budget and the salinity mean of Section B in the previous year from 1999 to 2020 is calculated. The correlation between observations and the predictions is 0.85 with the confidence level of 0.95, and the average of salinity difference is 0.4, as shown in Fig.10.

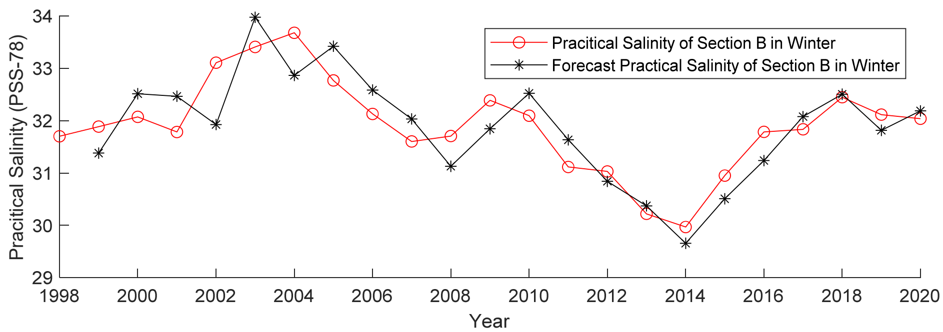

Figure 9. The mean salinity (°) of Section B in winter and the predicted salinity based on the freshwater budget of the Bohai Sea (*)

As shown in Fig.10, the freshwater supply of the Bohai Sea derived by the Yellow River runoff, evaporation, and precipitation in the previous year basically dominate the salinity change in the subsequent year, and also explains why the salinity of the central of Bohai Sea was higher than that of the Bohai Strait in 2001-2006, 2017, and 2018: the freshwater supply of the Bohai Sea continued to be negative from 2000 to 2002, resulting in the salinity of the Bohai Sea keep rising; although the freshwater budget of the Bohai Sea was positive from 2003, the net increase of freshwater supply was not enough to reduce the salinity of the central Bohai Sea to that of Bohai Strait until 2007 when the horizontal distribution of salinity return to the climate state again. In 2016 and 2017, along with the rising of the evaporation and decreased precipitation, the Yellow River runoff in this two years was lower than in previous years again, as shown in Fig.8, resulting in higher salinity in the central of Bohai Sea than that of the Bohai Strait in 2018 and 2019.

Since the average difference between the predicted salinity and the measured salinity is as high as 0.4 this algorithm is useful but relatively coarse, and there should be other factors to affect the salinity change in the Bohai Sea, such as the water exchange between the Bohai Sea and the Yellow Sea.

4.2 Freshwater budget of the Bohai, Yellow and East China Seas

The seawater of the Bohai, Yellow and East China Seas could be roughly considered as a mixture of two water masses, one is the fresher water mass along China coast formed by the runoff of rivers into the sea and the other is saltier water mass of the China offshore brought by the Kuroshio Current and its branches. The distribution characteristics of the salinity of Chinese offshore seawater are characterized by: fresher on the surface and saltier in the deep layer; fresher nearshore and saltier offshore; freshest in the estuarine and saltiest in the Kuroshio, as shown in Fig.3.

As the second strongest current in the world after the Gulf Stream, the Kuroshio originates from the northward branch of the North Equatorial Current in the Pacific Ocean after it reaches Luzon, acts as a natural barrier between North West Pacific seawater and the East China Sea seawater. Compared with the circulation in the Chinese shelf seas, the Kuroshio Current is more stable, more continuous and less seasonal variation. Therefore, this paper ignores the impact of its salinity variability on the Chinese offshore seawater.

As the largest river in China, the Yangtze River is the main body of China's coastal diluted water and its annual runoff discharging into the sea is maintained at 1012 m3 which is the same order of magnitude as the total water storage capacity of the Bohai Sea. In the flood season (summer), the Yangtze River's diluted water is forced by the southerly wind and pushed by the Taiwan Warm Current to the north, its water body shifts northward and most of water discharged to the sea are held near the Yangtze River estuary, as shown in Fig.3 c, d. In autumn and winter, the north wind strengthens, the solar radiation weakens, the cooling speeds up, the convection and eddy mixing strengthen, and the fresh water on the ocean surface is transported to the bottom, maintain the salinity of the Bohai, Yellow and East China Seas is significantly lower than that of Kuroshio Current and the ocean west of it, shown in Fig.3 a, b (Xiong, 2012).

Based on the ERA5 from 1959 to 2021, the annual average of freshwater budget of China offshore is negative north of 35°N and is positive in a fan-shaped area centered on the Yangtze River, from 34°N in the north to 27°N in the south and 127°E in the west, the maximum locates in the estuary of Yangtze River. Its isolines are in good agreement with the salinity contours Outside the mouth of the Yangtze River, as shown in Fig.11 and Fig.3.

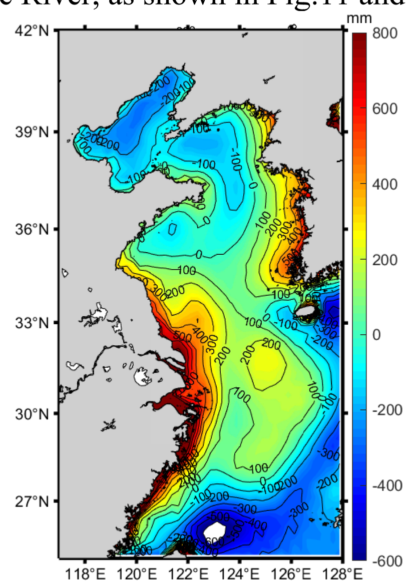

Figure 10. Annual average of freshwater budget from 1959 to 2020

To further understand the spatial and temporal characteristics of the interannual variation of freshwater budget for the Bohai, Yellow and East China Seas, 63 years of monthly average freshwater budget series from 1959 to 2021 were subjected to 12 months of low-pass filtering (to eliminate the effect of seasonal variation), and then the obtained annual components were subjected to an empirical orthogonal function (EOF for short) decomposition.

Table 1 The Eigenvalues and Percentages of the First Three Eigenvectors of Freshwater Budget of the Bohai, Yellow and East China Seas

Mode	1^{st}	2^{nd}	3^{rd}	Sum
Eigen value	475.4	390.8	239.5	1105.8
Percentage /%	28.52	23.45	14.37	66.33

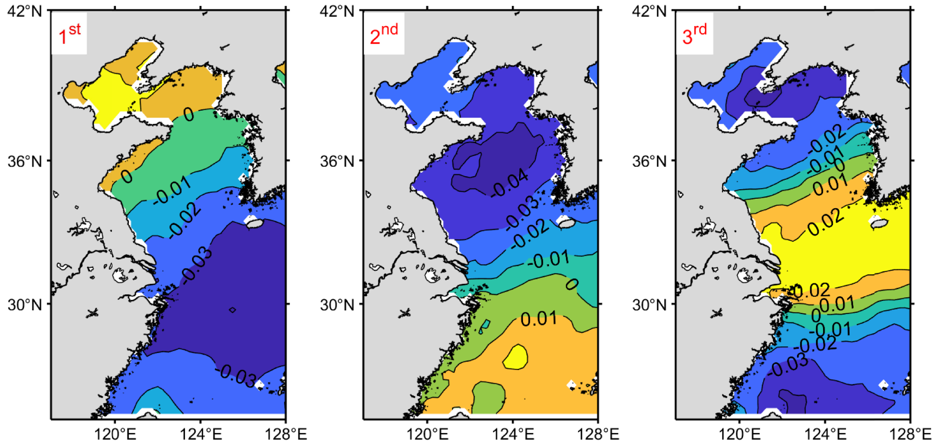

Figure 11. The first three spatial patterns of EOFs of freshwater budget from 1959 to 2021 in Bohai Sea, Yellow Sea and East China Sea.

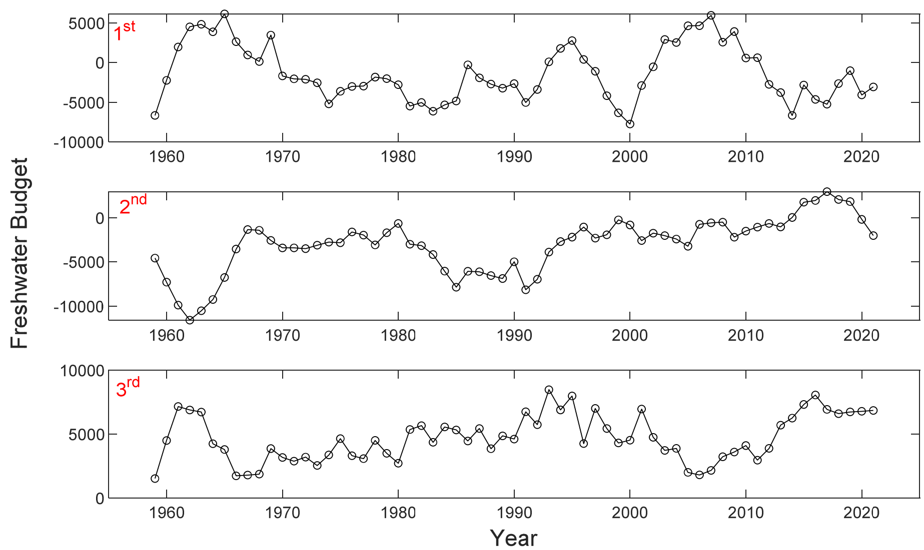

Figure 12. The first time coefficients of three temporal EOFs of freshwater budget from 1959 to 2021 in Bohai Sea, Yellow Sea and East China Sea.

As shown in Table 1 and Fig.12, the first three spatial EOFs are basically distributed along the latitude, showing a "seesaw" structure of north-south inverse phase oscillation, which is also the expression of the balance of freshwater in China's offshore, with an increase in the south and a corresponding decrease in the north, and vice versa. The first EOF explains 27.73% of the total variance, which is the main pattern of freshwater budget in the Bohai Sea, the Yellow and East China Seas. It is bounded by 34°N~36°N, with negative values south of the boundary and positive values north of it, indicating that when freshwater budget is increasing south of the boundary, it decreases north of the boundary. The coefficients of their temporal changes from 1998 to 2002, and from 2017 to 2019 are negative, shown in Fig.13, indicating that the freshwater balance of the northern Bohai Sea is negative and the freshwater balance of the southern Yellow Sea and the East China Sea is positive, thus leading to the increasing salinity of the Bohai Sea in these years and the decreasing salinity of its outer oceanic water, together with the insufficient exchange of seawater in the Bohai Sea, the cumulative effect leads to the increase of the salinity inside the Bohai Sea and causes this inverse phase of the salinity inside the Bohai Sea being higher than the salinity of the Yellow Sea.

4.3 Local ionic substance input to the Bohai seawater

From Section 4.1 and 4.2, it’s clear that the water exchange between the Bohai Sea and the open sea is very poor for the local freshwater budget dominate the practical salinity magnitude and distribution. As a semi-closed sea, the seawater chemistry data of the '06’s Investigation’ (Ji, 2016; Ji et al, 2021) show that nutrients and total alkalinity are significantly different from standard seawater which is affected by the discharge of the highly sandy Yellow River and the resuspension and dissolution of deposited calcium carbonate under the agitation of strong winds in winter.

Based on the standard seawater (Millero, 2008), the total alkalinity of Bohai seawater in winter was normalized,

$$\Delta[\text{NTA}] = \text{TA} - 2.3 \times \frac{S_P}{35} \tag{3}$$

In Eq. 3, the unit of TA is mmol·kg $^{-1}$, S_P is the practical salinity of seawater.

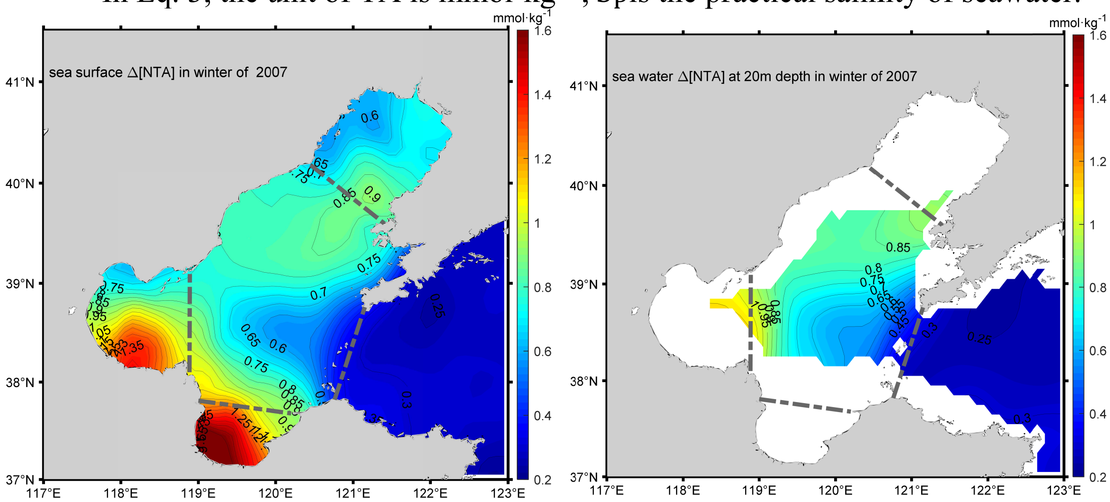

Figure 13. The contour of sea surface temperature and salinity of Bohai Sea in '06’s Investigation'

It can be found that the Δ[NTA] maximum value of 2.0 appears in the Bohai Bay and Laizhou Bay on both sides of the Yellow River estuary, and its isolines spill outward in an arc outward from the top of two bays, and the Δ[NTA] on the bottom layer is higher than that of the sea surface, as shown in Fig.14. A low Δ[NTA] tongue extends westward from the Bohai Strait, rising along its way, and its front could only reach the central of Bohai Sea which implies the fraction of intruding Yellow Sea water continues to decline from east to the west.

The practical salinity is derived from the measured conductivity, temperature and pressure of seawater by EOS-80 based on the rule of the constant relative composition of seawater. When the relative composition of seawater changes, differences appear in practical salinity and the mass of dissolved substances in seawater. As the seawater standard for the thermodynamic properties of seawater, TEOS-10（IOC et al, 2010）provides the equations to correct the difference of practical salinity between the mass of dissolved ionic content in seawater. The Absolute Salinity Anomaly δS_{A} in the whole Bohai Sea is always larger than 0.02 g·kg^{-1}. The largest δS_{A} of 0.20 g·kg^{-1} in the Bohai Sea appears on the bottom of the Laizhou Bay in winter (Ji et al, 2021).

Surrounded by land on three sides, the Bohai Sea carries the sewage discharged into the sea from three provinces and one city in northern China and is under great pollution pressure. In recent years, with the rapid development of the Bohai Rim Economic Belt and the lack of reasonable planning and management, the water quality in the Bohai Sea has continued to deteriorate. worsening, red tides occur frequently (Yu et at, 2000; Shang, 2015; Xu, 2020). However, the available data are still unable to accurately calculate the magnitude of the impact of these substances on the salinity of seawater.

5 Summery

Salinity is a key variable in the modelling and observation of ocean circulation and ocean-atmosphere fluxes of heat and water. Accurate characterization of seawater salinity is a requirement for exploring the mechanisms of local ocean environmental change.

Based on in-situ hydrographic measurements and reanalysis data over 35 years, this paper reveals the mechanism of that the practical salinity of the Bohai Sea in January 2007 was not only significantly higher than the multi-year mean, but also the horizontal distribution was opposite to the latter, as well as indicates it is necessary to replace the Practical Salinity with the Absolute Salinity for accurately study of salinity changes of the Bohai Seawater.

Due to the inhomogeneity of the temporal and spatial distribution of the measurements, this paper only treats salinity variation in the Bohai Sea as a whole, the in smaller spatial scale is ignored; the temporal scale of salinity changes of this study is only accurate to the year and on seasonal or smaller time scales are not considered; moreover, it does not qualify the water exchange between the Bohai Sea and the Yellow Sea. At present, a study on the characteristics and patterns of smaller temporal scale salinity changes in the Bohai Sea, combined with ocean models and other measurement data, is currently underway.

Due to material transport by runoff, re-dissolution and mixing of bottom materials, biological uptake and decomposition, relative composition of offshore seawater may be significantly different from that of the open ocean, and seawater salinity is no longer a conservative quantity. However, the available information cannot precisely calculate the magnitude and distribution change pattern of the impact of these dissolved material anomalies on the salinity of the Bohai Sea.

References

Chen, D.X. (1992), Marine Atlas of Bohai Sea, Yellow Sea, East China Sea, Hydrology. China Ocean Press, Beijing. 530 pp. (in Chinese).

Fan W., Xiang W., Wang H. (2021), China Oceanographic Hydrometeorological and Climatological Records—Bohai Volume [M], Beijing: Ocean Press

Fang G., Wang K., Guo F. (2002), The long-term changes of Bohai Sea hydrology and meteorological conditions and their relationship in the past 30 years, Ocean and Limnology, 22 (5): 515-55

GCOS 2010: Implementation Plan for the Global Observing System for Climate in support of the UNFCCC (2010 Update) (Geneva: World Meteorological Organization) WMO-TD/No. 1532 (GCOS-138) p 180 www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

IOC, SCOR and IAPSO (2010), The international thermodynamic equation of seawater - 2010: Calculation and use of thermodynamic properties. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English)[M], pp 196.

Jia R., Su J., Hu X. (2008), Temperature and salinity structure and changing trend of section B1 in Bohai Sea in summer, Journal of Ocean University of China, *Natural Science Edition*, 38(5): 705-711

Ji W. (2016), China Offshore Oceans—Marine Chemistry [M], Beijing: Ocean Press.

Ji F., Pawlowicz R., Xiong X.(2021) Estimating the Absolute Salinity of Chinese offshore waters using nutrients and inorganic carbon data, *Ocean Sci.,* 17, 909–918, 2021 https://doi.org/10.5194/os-17-909-2021

Lin C., Su J., Xu B. (2001), Long-term variations of temperature and salinity of the Bohai Sea and their influence on its ecosystem*, J. Progress in Oceanography*, 49:7-19.

Ma C., Wu D., Lin X. (2006), The interannual and long-term variation characteristics and causes of salinity in the Bohai Sea and the Yellow Sea, *Journal of Ocean University of China*, Natural Science Edition, 36(Sup.), 7-12

Ma C., Ju X., Wu D. (2010), Salinity distribution characteristics and changing trends of Yellow and Bohai Sea sections and marine stations, *Marine Science(in Chinese),* 34 (9): 70-81

Millero, F. J., Feistel, R., Wright, D. G., and McDougall, T. J.(2008), The composition of Standard Seawater and the definition of theReference-Composition Salinity Scale, *Deep-Sea Res.* Pt. I, 55,50–72.

Pawlowicz R., Feistel R., McDougall T. J., Ridout P., Seitz S., and Wolf, H. (2016), Metrological challenges for measurements of key climatological observables – Part 2: Oceanic salinity, *Metrologia*, 53, R12–R15, https://doi.org/10.1088/0026-1394/53/1/R12.

Shang X. (2015), A Numerical study of the Nutrient Ecosystem Dynamics in water layer of Bohai Sea, (in Chinese), Master's thesis of Ocean University of China.

State Oceanic Administration (2016), China Offshore Ocean Atlas - Physical Ocean [M], Beijing: Ocean Press.

Song W. (2009), Bohai Sea Temperature and Salt Field Structure and Current Characteristics Analysis in Winter and Summer, Master's thesis of Ocean University of China.

Wu D., Mou L., Li Q., Bao X., Wan X.(2004a), Long-term salinity variation characteristics and possible dominant factors in the Bohai Sea, *Advances in Natural Sciences,* 14(2):191-195

Wu D., Wan X., Bao X., et al. (2004b), Comparison of temperature and salinity field and circulation structure in Bohai Sea in summer of 1958 and 2000, *Science Bulletin*, 49(3): 287-292

Xiong X., China Offshore Oceans—Physical Oceanography and Marine Meteorology [M], Beijing: Ocean Press, 2012

Xu H.(2020), Regime shift of trophic status and nutrient criteria in the Bohai Sea, Ocean First Institute, Master Thesis (in Chinese)

Xu J. (2007), The Variarition Characters and Formation mechanism of salinity in the Bohai Sea, Ocean University of China, Master Thesis (in Chinese)

Yellow River Conservancy Commission of Ministry of Water Resource, Yellow River Water Resources Bullitin (2020), www. yrcc.gov.cn/zwzc/gzgb/gb/szygb

Yu H.,Bao X., Lü C., Chen X.,Kuang L. (2009), Analyses of the long-term salinity variability in the Bohai Sea and the northern Huanghai(Yellow)Sea, *Acta Oceanologica Sinica*, Vol.28, No.5, p.1-8

Yu Z., Mi T., Xie B. (2000) , Changes of the environmental parameters and their relationship in recent twenty years in the Bohai Sea, *Marine Environmental Science (in Chinese)*, Vol.1 9, No. 1, pp15~19

Zu T., Bao X., Xie J., Wu D. (2005), Distribution and change trend of environmental elements in the middle section of Bohai Sea*, Periodical of Ocean University of China (in Chinese),*35(6), 889-894

Zweng, M.M, J.R. Reagan, D. Seidov, T.P. Boyer, R.A. Locarnini, H.E. Garcia, A.V. Mishonov, O.K. Baranova, K.W. Weathers, C.R. Paver, and I.V. Smolyar (2019). World Ocean Atlas 2018, Volume 2: Salinity. A. Mishonov, Technical Editor, NOAA Atlas NESDIS 82, 50pp. This document is available on line at http://www.nodc.noaa.gov/OC5/indprod.htm