Title : Long-term variation of dissolved oxygen along a transect in the Bohai Sea over 40 years

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1. Aim:

This study aimed 1) to revealed the inter-annual variation of DO concentration in the central section of Bohai Sea from 1978 to 2018; 2) to influencing factors of the inter-annual variation of DO were found by using multiple linear regression.

2. Procedure:

This paper uses the observation data obtained from 1978 to 2018 by the Marine Survey Team of the North Sea Branch of the State Oceanic Administration and the North Sea Environmental Monitoring Center, including temperature and dissolved oxygen. The study area is the central section of Bohai Sea (the study area and the observation stations are shown in Fig. 1), and the sea area ranges from 37.0-40.5 ° N and 117.0-121.65 ° E. The stations are distributed from the southwest (near the Yellow River Mouth) to the northeast (near the Liaohe Mouth). The stations are divided according to the water depth and location of each station. St1, St8 and St9 are estuaries, St4 and St5 are central shoals, and St2, St3 and St5 -- St7 are middle depressions.

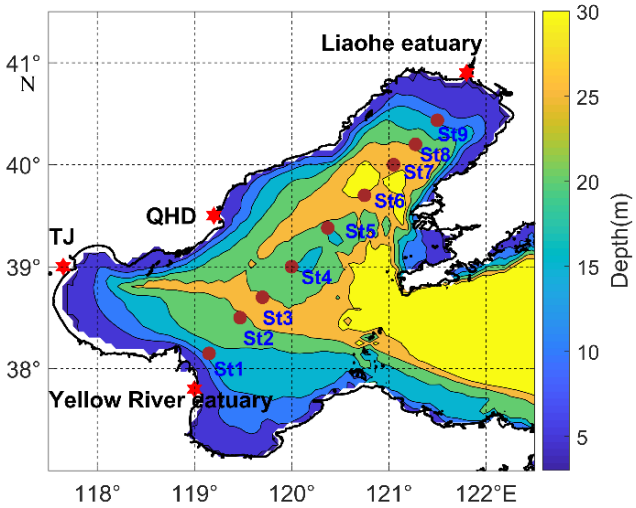

FIG . 1 Observation station position and water depth distribution

In this paper, the annual average data of St1-St9 stations are used to analyze the seasonal characteristics of DO and temperature. February and August represent winter and summer respectively. Interpolation method was used to process the measured values into 1m average data and draw the sectional view. Linear fitting method was used to analyze the interannual variation characteristics of DO in winter and summer.

In this paper, the data of surface chlorophyll concentration from the Yellow Sea and the East Sea from 1998 to 2019 were used for local correction (Wang et al.,2021) with a

resolution of 4km×4km. Wind, precipitation and runoff data come from ERA5 global monthly reanalysis data provided by the European Center for Medium - Range Weather Forecast (ECMWF). The spatial resolution of wind speed data is 0.125° ×0.125° , and the temporal resolution is 6h. The spatial resolution of precipitation and runoff data is 0.25° × 0.25° .

3. Result

3.1 Interannual variation characteristics of DO

The interannual variation of DO concentration and spatial distribution in winter and summer in recent 40 years was studied in this paper. In summer, ground floor DO showed a decreasing trend, and there were spatial differences among stations . Stations St2 -- St3 and St5 -- St7 near the two depressions in the middle of the region decreased significantly. The values of St1 and St9 near the shore fluctuated little over the years, while the values of St4 in the central shoal changed little and were high (as shown in Fig. 2) .The range of DO in the bottom layer in summer is 2.27-9.23 mg/L, with an annual mean of 5.99mg/L. The mean values of St2, St3, St5 and St6 in the central depression are relatively small, and the smallest station is St2, which is 5.69mg/L. The mean values were 5.12mg/L, 4.86mg/L and 4.67mg/L in the past 30, 20 and 10 years, respectively.

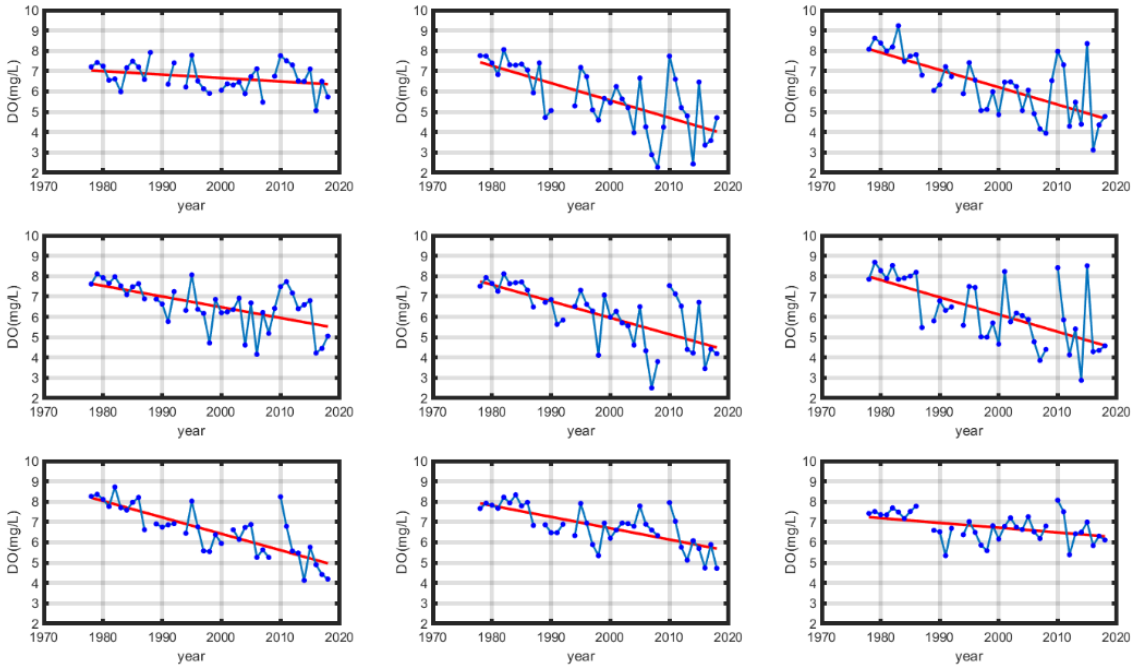

FIG . 2 St1−St9(Blue represents the line of scatter plot of DO values for years at each station, and the red line represents the linear fitting line of data at each station)

In summer, there is no obvious trend of surface DO (As shown in Fig. 3), and perennial DO varies from 5.65 mg/L to 10.50mg/L, with an average of 7.49 mg/L. The St1 and St9 near the estuary showed a decreasing trend, which was related to the higher temperature in the estuary.

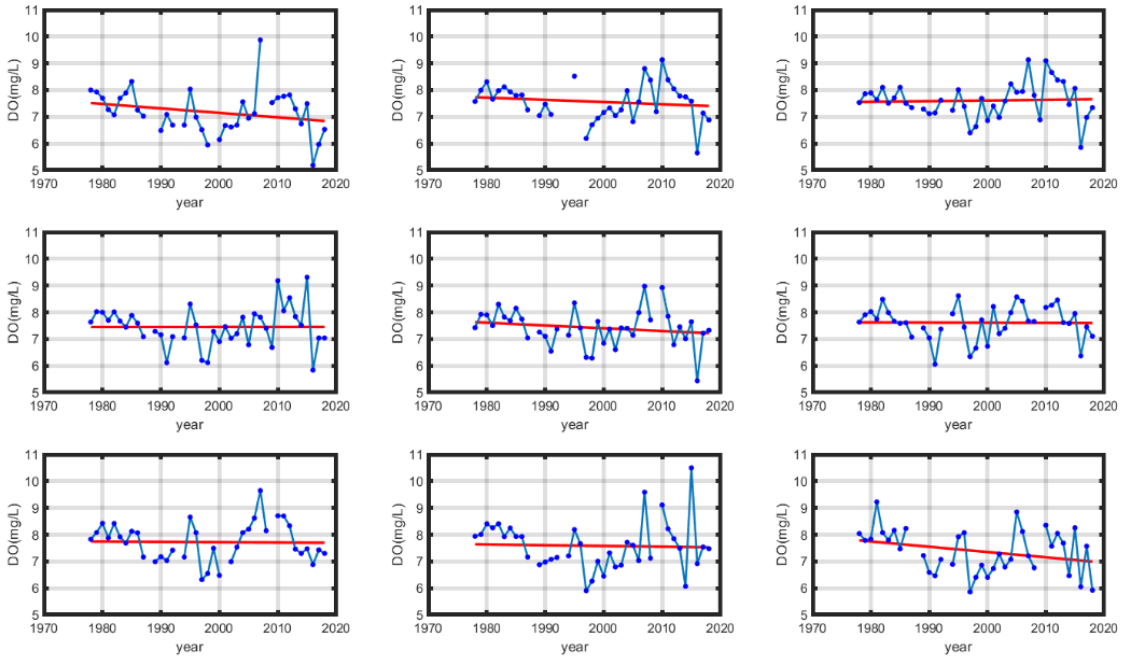

FIG . 3 Perennial variation of surface DO in summer of St1 -- St9

The inter-annual variation of DO spatial distribution in the central section of Bohai Sea is shown in Fig. 4. The inter-annual variation of DO spatial distribution in August of Bohai Sea significantly decreases, and the range of low values is also expanding.

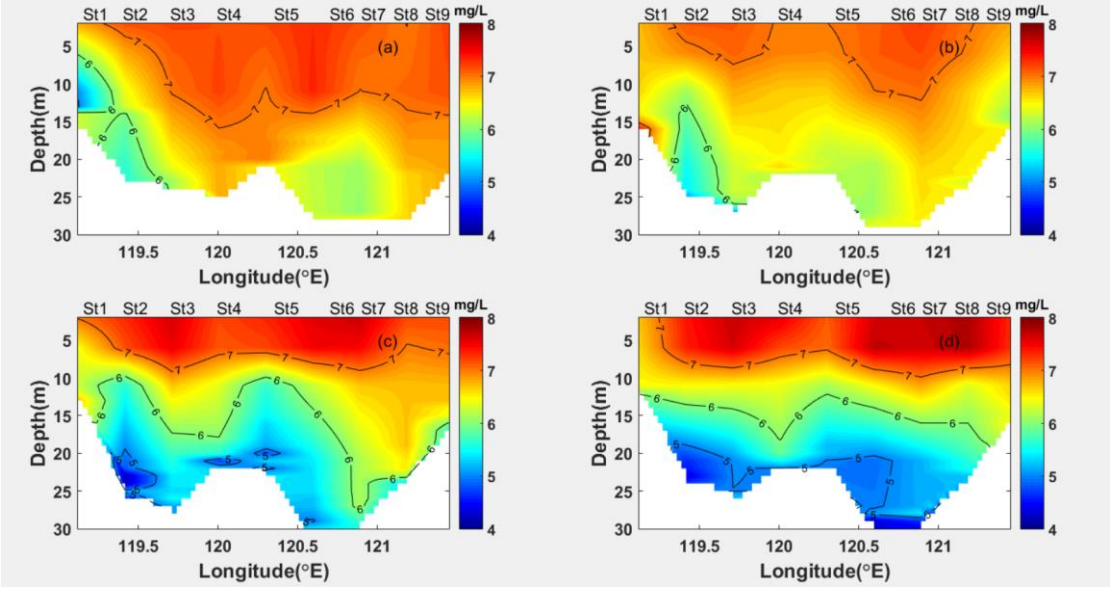

FIG . 4 Sectional diagram of mean values of St1 -- St9DO in each decade (Figure a-d is the mean values of 1978-1987, 1988-1997, 1998-2007 and 2008-2018 respectively)

3.2 Analysis of influencing factors

The winter table is shown in Figure 3-5, and the difference at the bottom of the DO table has obvious interannual variation, which is reflected in the rise of the surface value and the decline of the bottom value. Zhai Weidong believes that the occurrence of the low DO value

at the bottom is related to the seasonally stratified phenomenon blocking the air-sea exchange(Zhai et al .,2012）. Zhang Hua believes that the DO value at the end of 2014 is basically consistent with the bottom double-center cold water structure(Zhang et al .,2016）. At the same time, the mineralization and decomposition of organic matter accumulated in the bottom sediments in summer is an important cause of low oxygen at the bottom (Zhang et al .,2016）.In addition to the interannual variation of DO table bottom difference caused by the low DO bottom value, the Yellow River runoff also has an impact on the interannual variation of DO. Shi Qiang believes that the stations near the Mouth of the Yellow River lag significantly with the interannual variation of DO in the Bohai Sea(Shi et al .,2016）. Jiang Tao believed that chla and phosphate high-value areas and low-oxygen areas partially overlapped in surface water(Jiang et al .,2016）.

In this paper, several typical stations representing the southern depression (St2), the central shoal (St4, St5) and the northern depression (St6) were selected to conduct multiple linear regression analysis with DO data from 2000 to 2018, and to discuss the factors influencing the interannual variation of DO.

The results showed that in summer, DIN at the bottom of St2 affected 41.59% of the annual variation of DO (R^2 = 0.4159, p < 0.01), and 70% (R^2 =0.7, p < 0.01) could explain the annual variation of DO if silicate, phosphate, rainfall and Yellow River runoff were taken into account. The underlying temperature of St4 can explain 32.93% of the inter-annual variation of DO (R^2 =0.3293, p< 0.05), and 39.23% (R^2 = 0.3923, p< 0.05) after considering runoff. The underlying DIN of St6 accounted for 39.16% of the inter-annual variation of DO (R^2 = 0.3916, p< 0.05)., 60.29% (R^2 = 0.6029, p< 0.05) could be explained by increasing wind, silicate, surface temperature difference and bottom temperature.

In summer surface layer, taking runoff, rainfall, wind, chlorophyll, DIN, silicate and phosphate into consideration, St2 surface layer could explain 80.87% inter-annual variation of DO (R^2 = 0.8087, p < 0.05). 78.73% of St1 surface layer could be explained by taking into account runoff, DIN, chlorophyll, silicate and phosphate (R^2 = 0.7873, p < 0.01), and 33.33% of St6 surface layer chlorophyll (R^2 = 0.3333, p < 0.01) affected the interannual variation of DO. In St5, Yellow River runoff and chlorophyll accounted for 41.89% of the variation of DO (R^2 = 0.4189, p < 0.05).

In winter, the DO concentration at the bottom of the surface has a similar inter-annual change, and the DO saturation at the bottom of the surface is above 99% for many years, which is close to saturation . Shi Qiang pointed out that the change of winter water temperature mode is the main factor affecting the inter-annual variation of DO in the Bohai Sea in winter (Shi et al .,2014）, there is a strong negative correlation between DO and temperature in the surface in February, and the correlation coefficients of stations except St2 and St9 are all above 0.6. The inter-annual variation of DO in winter is related to the relationship between temperature influencing saturation . There is a negative correlation between the solubility of dissolved oxygen and water temperature, that is, when the water temperature is low, the solubility of dissolved oxygen is large and the saturation is high(Cong et al .,2019）.

4. Conclusion

1. In terms of inter-annual variation, the DO in the bottom layer decreased significantly in summer with spatial differences, and the decrease degree was greater in the two depressions in the north and south, while the DO in the surface layer had no obvious change trend in summer.

2. Spatially, the multi-year variation of DO in summer is characterized by significant difference at the bottom of the table, and the low value center of the bottom is getting lower and lower, and the range of low value is also expanding.

3. Multiple linear regression analysis showed that the interannual variation of summer DO in the bottom layer was affected by DIN.

5 Perspectives in future

We will further study the factors influencing the change of dissolved oxygen in Bohai Sea,and will continue to update the data collection of dissolved oxygen in the Bohai Sea, so that more accurate results can be obtained.