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Climate response and spatial-temporal model on the inter-annual change of winter temperature-salinity in the East China Sea

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Abstract: Spatial distributions and time variation characteristics were analyzed using Rotated Empirical Orthogonal Function (REOF) and spectrum analysis methods using surface and bottom temperature and salinity data in February of 1976-2013 along 30°N section in the East China Sea. Result showed that temperature trends can be divided into western part and east part, salinity trend divided into western, middle and eastern part. The first mode of surface temperature presented a quasi-equilibrium trend and the range was higher in the near-shore than the offshores, first mode of bottom temperature presented a decreasing trend; surface salinity had a decreasing trend and the extent was higher in the near-shore than the offshores, the bottom salinity showed a decreasing trend in recent years. The temperature inter-annual variability related to El Niño closely; short-term shocks of salinity related to El Niño, and long-term changes had something to do with PDO.

1. Introduction
Located to the east of China, East China Sea (ECS) is a marginal sea of the western Pacific. Surrounded by the Chinese mainland, Taiwan Island, Korean Peninsula, Kyushu and Ryukyu Island, its average depth is 349m and the maximum depth is 2719m. With a vast continental shelf in the west and a trough in the east, ESC has both the deep and shallow sea characteristics. The west bank, which is consisted of China's Fujian, Zhejiang and Taiwan west coast, has numerous ports and bays, the largest of which is Hangzhou Bay. While in the east, from Kyushu to Okinawa and east Taiwan there are many straits, waterways communicating with the Pacific Ocean. In the past century, the Earth's climate is characterized by a period of significant changes of global warming, which means a warming of both the atmosphere and sea. Temperature rise resulted lack of oxygen which is essential for creatures such as fish, threatened the marine life in the currently and future [1]. Rise of temperature reduces the number of marine phytoplankton plants in the form of microorganisms, while the fall increases the number of marine plants [2]. The accurate study of the ocean thermohaline helps to improve our understanding of marine ecosystem change. The equatorial Pacific Ocean plays an important role and as an indicator in the global climate system. Kuroshio and its branches, which come from the North Equatorial Current northward branch, transported the warm equatorial waters to the ECS and exert a severe impact on the water temperature there [3,4]. Sea surface temperature anomaly in ECS has a close relationship with Nino3.4 Index. Therefore, variations of the East China Sea thermohaline is an important part in the regional response to global climate change. ECS marine environment factors had been extensively studied during the past decades. CODAS SST data from 1951 to 1996 was used to study the East China Sea continental margin inter-annual temperature and
decadal variation, indicating that phase transformation occurs of the region SST on decadal scales and noting that the phase transformation related with western equatorial Pacific [5]. Thermohaline distribution of 32°N section was analyzed and found that this region exist an obvious thermocline in spring. In autumn the bottom cold water has a trend moving to the east. In the east part of the section, a high salt water intrusion presents at the bottom and the isohaline has a vertical distribution [6]. Interannual variation of SST of ECS was studied using AVHRR data and discussed its relationship with East Asian monsoon interannual variation [7]. The possible mechanism of seasonal distribution and change of SST in East China Sea was analyzed based on satellite remote sensing SST data [8-11].

The research on the climate response and spatial-temporal distribution on the inter-annual change of temperature-salinity in the last four decades will help to understand the local spatial-temporal structure of wither time ECS and further find out the impact of other biochemical factors.

2. Data and Methods

2.1. Data source

11 Monitoring stations of 30°N section located in the ECS continental slope, substantially equal-spaced (Figure 1). The westernmost section depth is approximately 60 meters and easternmost 400 meters. From 1976 to 2013, the State Oceanic Administration (SOA) monitored the temperature and salinity at the surface and bottom of this section in the winter (February). An Ocean Station-Dajishan, attached to SOA, located near the east end of the section, has collected hydrometeorology data from 1978.

![Figure 1. Section stations location, red points are section stations, green point is ocean station Dajishan](image)

2.2. Methods

2.2.1. Rotated empirical orthogonal function. Rotated empirical orthogonal function (REOF) method is an improvement of empirical orthogonal function (EOF). EOF is a method to analyze data structure of the matrix and extract the main spatial and temporal characteristic [12, 13], which can reflect the overall spatial-temporal change of the region. When it comes to analyze the S-T structure of regional variables, REOF is a suitable method.

2.2.2. Jump analysis method Signal to noise ratio (SNR) formula was used to determine the intensity and time when time jump occurred within a time-series data[14]. SNR formula is as follows:
\[ J = \frac{|M_1 - M_2|}{\sigma_1 + \sigma_2} \]

Where \( M_1, M_2 \) and \( \sigma_1, \sigma_2 \) are mean and standard deviations before and after the reference time, respectively. When the local maximum ratio appears more than 1.0, the jump phenomenon occurs. In this study, the time scale \( n \) is set at 15 years.

2.2.3. Normal Distribution Test and Nonlinear Correlation Coefficient
When the sample sequence follows a normal distribution, the sample mean could be used as the statistical characteristics of a sample sequence. In this paper, unless special stated, the calculated means of temperature and salinity all have passed normal distribution kurtosis and skewness coefficient criterion test.

Nonlinear correlation coefficient is defined as the ratio of explainable variation to total variation. It ranges from 0 to 1. The explainable variation is calculated using the second-order polynomial fitting. If the highest order of polynomial is reduced from 2 to 1, the nonlinear correlation coefficient degenerates into linear correlation coefficient.

3. Results and discussion

3.1. Annual trends of climatic factors and SST & salinity
The long-term trend is analyzed by averaging air temperature in February and mean value of zonal and meridional wind stress in January of Dajishan Ocean Station of ECS, using Five Gaussian Low-pass Filter method. And the average air temperature in February has a significant linear increase trend (Figure 2); average meridional pseudo-wind stress in January has a significant linear weakening trend (Figure 3), average zonal pseudo-wind stress in January has a non-significant linear weakening trend (Figure 4). The climatic trend of increasing winter temperature and weakening intensity of northwest monsoon will affect the interannual changes of temperature and salinity structure in the ECS.

Figure 2. 5 Gaussian low-passes filtering of temperature in Feb of DJS
The temperature and salinity data sequences were smoothed along the temporal direction to reduce short-wave noise.

As surface and bottom temperature distribution shown(Figure 5), the temperature experienced changes of cold period (1976-1985), warm period (2005-1986) and cold period(2006-2013), in which 2005 was the warmest and 2012 the coldest. Temperature presents a trend of low in the west section and high in east. Especially, affected by the Kuroshio, temperature in the easternmost is highest.

For salinity (Figure 5), it appears that between 1976 and 1985 there was an obvious low salinity period and in 2002 the salinity was highest. Low salinity water located in the middle of section and highest salinity in the eastern, also indicating the influence of high salinity water brought by Kuroshio.

The average variation character of section temperature from 1976 to 2013 is obtained by obtaining average surface temperature anomaly (figure 6). Meanwhile, to reduce the impact of extreme events on long-term trend, anomalies were averaged using 5-point sliding method. In the past 4 decades, the variation of winter SST anomalies is very intense, varied from $-2 \sim 2.4^\circ C$. The minimum SST occurred in 1977 while the maximum in 1984. Prior to 1997, there were negative and positive anomalies both, but after 1997 there were basically all positive anomalies. The strongest negative anomalies occurred in 1977, 1982 and 1986. The most significant positive anomalies occurred in 1979, 1984, 1999 and 2009, respectively. These two periods correspond to the strong El Niño and La Nina years.
Figure 6. Inter-annual variation of surface and bottom temperature anomaly (blue and red solid line for surface and bottom temperature initial anomaly respectively, blue and red dotted line for surface and bottom temperature moving average anomaly respectively)

Similar averaging is implemented to salinity, (figure 7) resulting surface salinity anomaly varies from -0.58 to 0.53, with the maximum positive anomaly occurred in 1987 while the largest negative anomaly in 2008. 1998 is the dividing line between positive and negative anomalies, i.e. a positive anomaly before and a negative anomaly after.
3.2. Temperature interannual temporal and spatial variation of surface and bottom layer

REOF was adopted to analyze temperature anomaly sequence data of surface and bottom layer (figure 8-9), the first 2 terms are taken out to do rotation transformation, and Gaussian low-pass filtering was used to eliminate short-term disturbances for time component. The REOF first mode (REOF1) accounted for 58% of the proportion, which is the main form of temperature anomalies. Combined with the time series, we infer prior to 1997, the anomalies is mainly negative and after that is positive and show a warming trend.

To test whether the turning point reach the abrupt climate change standards, the signal-noise ratio was calculated using average and standard deviation of 15 year data before and after 1997. Result shows the ratio was 1.17, and it is greater than 1, which indicated that the year 1997 was surely abrupt climate change standards.

Magnitude of Temperature anomaly wanes from nearshore to open sea. By analyzing the power spectrum of time series, we can get the main change cycle: 4.8 years, 5.9 years and 3.6 years. And 4.8 year is most obvious.

REOF1 indicated that SST shows a warming trend in 1976-2013, and the offshore magnitude is larger than that in the opens, with main period of changing cycle of 4.8 years.
3.3. Climate response of SST

Delay-lag analysis was made between DJS ocean station air temperature in February and the first and second time mode of section SST (figure 10). A significantly positively correlated response is found, each mode has three peaks. Delay / advance at the peak may associate with the Kuroshio.
Delay-lag analysis was made between DJS ocean station Pseudo wind stress in January and the first and second time mode of section SST (figure 11). Result shows a non-significantly positively correlated response with the first mode, but didn’t relate with the second mode. That means the first mode of SST was affect by wind and the signal is 1 month delay.

3.4. Salinity interannual temporal and spatial variation of surface layer
REOF was adopted to analyze salinity anomaly sequence data of surface and bottom layer, the first 2 terms are taken out to do rotation transformation (figure 12-13). Then Gaussian low-pass filtering was used to eliminate short-term disturbances for time component.

The REOF first mode (REOF1) accounted for 45.3%, which is the main form of salinity anomalies. Combined with the time series, the anomalies is mainly negative, but in 2002-2003 there were two big positive and then shift to negative,

Therefore, prior to 1997, the anomalies are mainly negative and after that turned to positive and showed a warming trend. That is to say that salinity has went through a decreasing trend.

Away from the shore, salinity anomaly showing negative-positive trend-0; The REOF second mode (REOF2) take up 27.1%. Positive salinity anomaly decreases when getting offshore. Time factor shows a roughly positive-to-negative trend.

By analyzing the power spectrum of time series, two main change cycles of 15.4 years and 34.1 years show. And 15.4 year is most obvious. So REOF1 means between 1976 and 2013 salinity of the surface shows a decreasing trends, and the offshore decreasing magnitude is larger than that in the opens, the main period of changing cycle is 15.4 years.

Figure 12. Spatial mode of surface salinity anomaly

Figure 13. Time-varying coefficients of the first two modes of surface salinity
3.5. Climate response of sea surface salinity

Salinity, especially surface salinity, has a direct relationship with precipitation, and ENSO has an effect on precipitation, so ENSO will affect salinity. Generally speaking, rainfall amount in the North area of China will decrease, if we compare surface salinity with Nino 3.4 index after standardization (figure 14), a significantly positively correlated response is found, the correlation coefficient is 0.66, which means surface salinity increase in the El Niño year and is consistent with decrease of rainfall. However, the correlation is not good after 3 year filtering, which means short term shock of salinity may related with El Niño. Then when comparing salinity after 3 year filtering with PDO index(figure 15), we found that there is a significantly positively correlated response with correlation coefficient is 0.74, which means the outer-annual scale change has a relationship with signal from out seas.

![Figure 14. Inter-annual variation of surface average salinity and Niño3.4 Index](image)

![Figure 15. Inter-annual variation of surface average salinity and PDO Index](image)

4. Conclusions

The temperature experienced changes of cold period (1976-1985), warm period (2005-1986) and cold period (2006-2013), in which 2005 was the warmest and 2012 the coldest. Temperature presents a trend of low in the west section and high in east. Especially, affected by the Kuroshio, temperature in the easternmost is highest.

For salinity, it appears that between 1976 and 1985 there was an obvious low salinity period and in 2002 the salinity was highest. Low salinity water located in the middle of the section and highest salinity in the eastern.
We infer prior to 1997, the anomalies are mainly negative and after that are positive and show a warming trend, and the offshore magnitude is larger than that in the opens. The main change cycle of the first mode is 4.8 years, 5.9 years and 3.6 years. SST has a significantly positive response with air temperature with ocean station nearby, also it was affect by wind and the signal is 1 month delay.

The salinity has gone through a decreasing trend. Away from the shore, salinity anomaly shows negative-positive trend-0. The main change cycle of the first mode is 15.4 years and 34.1 years. Short term change has a relationship with ENSO and long term change has a significantly positively correlated response with PDO index.

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