The interannual trend and preliminary quantitative estimation of the oceans condition in the Bohai Sea area

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Abstract. After different frequency observed temperature data of Bohai sea marine observation stations was analyzed, results showed that daily average sea surface temperature value obtained from 3-hour-observations (08h, 14h, 20h) which was slightly lower than that from 24-hour-observations. The general gap was within 0.10 ℃, while the value was 0.05 ℃ for the monthly mean temperature. Daily average sea surface temperature values of 3-hour-observations have a little effect both in statistical properties and the accuracy of statistical data, which does not affect the representativeness of the data. It can be used in studying long time series problems. Analyzing the trend of the SST data changes in 1960-2012 and the SAT data changes in 1965-2012 by using the linear tendency estimate and cumulative distance square method, it can prove that SST annual variation rate was 0.010 ℃/a, with a total increase of 0.53 ℃ in last 53 years; and SAT annual variation rate was 0.043 ℃/a, with a total increase of 2.06 ℃ in last 48 years. Although the long-term trend of these two factors is significantly increased, but there was a significant mutation around 1987. From 1960 to 1987, it had a downward trend, after 1987 it began to grow, the upward trend has not diminished until 2009.

1. Introduction
Bohai Sea is a continental enclosed sea which lies in north of China, its mean depth is 18 meters and the deepest area is located in Laotieshan channel with a depth of 86 meters [1]. The seawater exchange between the Bohai figure Sea and the Yellow Sea through the Bohai Strait, and it is more difficult to exchange with the deep sea outsides. At the same time, the coastal areas of Bohai is densely populated and within industrial development, and it is also a very active area with human economic activities. The status of its marine hydrology has become a concern [2].

In this paper, based on the representation of sea surface temperature (SST), the long-term trend of the basic hydrometeorological elements (SST and sea surface air temperature(SAT)) in the Bohai sea were analyzed by using recent 50 years of long-term continuous observation data of the oceanic stations. Calculated the elevating trend of annual variation rate and diagnosed roughly time of its mutations, which is helpful to deepen understanding of hydrological and meteorological conditions changes, is beneficial to the evaluation and analysis of the marine environment in Bohai Sea.

2. Basic Information
The observation data of oceanic stations is widely used because of the characteristics of long-term, continuity and near-shore. The practical value and application significance are obvious. When long time series data are needed, the importance and valuable information of oceanic station data are more
obvious. The study of marine hydrometeorological elements (such as SST, SAT, etc.) has always been a traditional subject in marine field and has been chosen as a decisive factor by other disciplines [3-13]. These elements have long been the basic observation items of oceanic stations for a long time. Therefore, it is very important to research and analyze the hydrometeorological data of oceanic station, which is very important for marine development and ocean engineering.

In this paper, we have selected more than 50 years, observation data of eight oceanic stations along the Bohai Sea (stations A-G, Figure 1). Analysed SST and SAT in 1960-2012(Table.1) has the most closed relationship with the ecological environment. The SST data is limited because of the freezing sea water in winter, so there is no observational data. Therefore, only the months without frost are recorded for calculating annual mean. For example, the annual average value of station C is the average value of 9 monthly mean average values (from Apr to Dec). The annual average values of the other 3 stations(D, E and F) are the average values of 10 monthly mean average values(from Mar to Dec). The annual average value of station A is the average value of 7 monthly average values (from May to Nov). Although the average annual value of SST is higher than the real situation, the results of this study have a little effect for the long-term trend of the study [4].

![Figure 1. Locations of the Bohai Sea marine observation stations](image)

| Stations | SST(Timing) | Data length | SAT(Timing) | Data length |
|----------|-------------|-------------|-------------|-------------|
| A        | 1960-2012   | 53          | 1965-2012   | 48          |
| B        | 1960-2012   | 53          | 1965-2012   | 48          |
| C        | 1963-2012   | 50          | 1965-2012   | 48          |
| D        | 1960-2012   | 53          | 1965-2012   | 48          |
| E        | 1960-2012   | 53          | 1965-2012   | 48          |
| F        | 1960-2012   | 53          | 1965-2012   | 48          |
| G        | 2011-2012   | 2           | 2008-2012   | 5           |
| H        | 2011-2012   | 2           | 2008-2012   | 5           |

3. The influence of observational frequency on SST statistical characteristics continuity

In the 1950s, due to observation conditions, SST was achieved artificially in a long time. The "Beach Observing Standard" (GB/T 14914-1994) [13] was implemented in 1994, stipulated for the timing observation clearly: "Sea surface temperature should be observed at 08h, 14h, 20h every day.” These three times represent the SST of the morning, noon and night respectively. Although they are representative, they are lacking continuity and cannot realize the daily continuity of SST of the oceanic stations. The daily mean values of the SST can be calculated by three times of observations, which may lead to the low or high daily mean value due to the maximum or minimum water temperature. Therefore, in the revised "Beach Observing Standard" (GB/T 14914-2006) [14] in 2006,
it is required to keep the original SST timing observation, and to equip with automatic observation equipment to make the SST continuous observations.

Since 1950s, the oceanic station has been using SWY1-2 type sea surface temperature measuring instrument (made by National Ocean Technology Center) to measure the SST, the measurement accuracy is ±0.1°C. For the continuous, only the last 10 years of data have the hourly SST data. So in some research of long time series, it can only be studied depends on the timing of observation data. However, due to the frequency of observation is less, statistical characteristics of the daily average SST, which calculating with 3 moments SST, should be demonstrated and analyzed.

Using two consecutive years (2011-2012) timing and hourly SST data of 7 oceanic stations (station A, stations C to H) in the Bohai sea area, we calculate the 3 moments daily average SST ($\bar{T}_4$) and 24 moments daily average SST ($\bar{T}_{24}$) respectively. And then calculating the monthly average SST $\bar{M}_4$ and $\bar{M}_{24}$ by $\bar{T}_4$ and $\bar{T}_{24}$ respectively, we do the comparative analysis. Specially, the calculation of the $\bar{T}_4$, SST on the 08h should be count twice. Such as follow [15]:

$$\bar{T}_4 = \frac{2t_0 + t_14 + t_20}{4}$$

In the course of the calculation, we select the complete data of the natural day to measure the statistics. The natural day is counted as an effective number of days, when $\bar{T}_4$ and $\bar{T}_{24}$ both have statistical results. The effective number of days is up to 731 days of 2011-2012. Specific comparison results are in Table 2 and Table 3. ($\Delta = \bar{T}_4 - \bar{T}_{24}$)

| Station | Effective Days(d) | $\Delta_i > 0$ | Percentage (%) | $\Delta_i < 0$ | Percentage (%) | $\Delta_i = 0$ | Percentage (%) |
|---------|------------------|----------------|---------------|----------------|---------------|----------------|---------------|
| A       | 731              | 202            | 27.63         | 407            | 55.68         | 122            | 16.69         |
| C       | 696              | 342            | 49.14         | 328            | 47.13         | 26             | 3.74          |
| D       | 731              | 156            | 21.34         | 504            | 68.95         | 71             | 9.71          |
| H       | 484              | 130            | 26.86         | 297            | 61.36         | 57             | 11.78         |
| E       | 587              | 131            | 22.32         | 408            | 69.51         | 48             | 8.18          |
| F       | 725              | 162            | 22.34         | 501            | 69.10         | 62             | 8.55          |
| G       | 477              | 194            | 40.67         | 255            | 53.46         | 28             | 5.87          |
| Total   | 4431             | 1317           | 29.72         | 2700           | 60.93         | 414            | 9.34          |

| Station | Effective Days(d) | $|\Delta_i| < 0.05$ | Percentage (%) | $0.05 \leq |\Delta_i| < 0.10$ | Percentage (%) | $|\Delta_i| \geq 0.10$ | Percentage (%) |
|---------|------------------|----------------|---------------|----------------|---------------|----------------|---------------|
| A       | 731              | -0.014         | 635           | 86.87          | 80            | 10.94          | 16            | 2.19          |
| C       | 696              | 0.001          | 246           | 37.19          | 156           | 47.75          | 294           | 42.24         |
| D       | 731              | -0.045         | 445           | 60.88          | 141           | 19.29          | 145           | 19.84         |
| H       | 484              | -0.018         | 372           | 76.86          | 78            | 16.12          | 34            | 7.02          |
| E       | 587              | -0.038         | 369           | 62.86          | 124           | 21.12          | 94            | 16.01         |
| F       | 725              | -0.031         | 464           | 64.00          | 162           | 22.34          | 99            | 13.66         |
| G       | 477              | -0.023         | 221           | 46.33          | 92            | 19.29          | 164           | 34.38         |
| Total   | 4431             | -0.024         | 2752          | 62.11          | 833           | 18.80          | 846           | 19.09         |

The number of effective days is a lot in stations A, C, D and F. The data is integrated. While the number of effective days is relatively less in stations H, E and G, this is still exceeding 65% of the total sample. The results have a certain degree of credibility. From Table 2 and Table 3, it is not difficult to see that, $\bar{T}_4$ is slightly smaller than $\bar{T}_{24}$, the difference value $\Delta$ between them is very
small. 62.11% of the difference value is within 0.05°C, the difference value within 0.10°C accounts for 80.91%.

On the basis of this, three stations (station A, D and F) with the highest number of effective days were selected and the monthly average SST is continued to be calculated. From Table 4, the results showed that the difference between $\bar{M}_4$ and $\bar{M}_{24}$ was within 0.05°C, the correlation coefficients were as high as more than 99.99%.

### Table 4. Statistical results of monthly average water temperature difference

| Year | Month | A  |   | D  |   | F  |   | A  |   | D  |   | F  |   | A  |   | D  |   | F  |   |
|------|-------|----|---|----|---|----|---|----|---|----|---|----|---|----|---|----|---|----|---|
|      |       | $M_4$ | $M_{24}$ | $\Delta_2$ | $M_4$ | $M_{24}$ | $\Delta_2$ | $M_4$ | $M_{24}$ | $\Delta_2$ | $M_4$ | $M_{24}$ | $\Delta_2$ | $M_4$ | $M_{24}$ | $\Delta_2$ | $M_4$ | $M_{24}$ | $\Delta_2$ |
| 2011 | 1     | -0.90 | -0.89 | -0.01 | -1.50 | -1.49 | -0.01 | -1.00 | -0.98 | -0.02 | 9.0 | 9.14 | -0.04 | 14.70 | 15.05 | -0.05 | 15.70 | 15.75 | -0.05 |
|      | 2     | -0.90 | -0.90 | 0.00  | -1.00 | -0.98 | -0.02 | -0.60 | -0.56 | -0.04 | 14.70 | 15.05 | -0.05 | 14.70 | 15.05 | -0.05 | 15.70 | 15.75 | -0.05 |
|      | 3     | 2.30  | 2.31  | -0.01 | 2.70  | 2.73  | -0.03 | 3.50  | 3.53  | -0.03 | 8.50  | 8.51  | -0.01 | 9.0  | 9.14  | -0.04 | 14.70 | 15.05 | -0.05 |
|      | 4     | 8.50  | 8.51  | -0.01 | 9.30  | 9.35  | -0.05 | 9.10  | 9.14  | -0.04 | 14.70 | 15.05 | -0.05 | 14.70 | 15.05 | -0.05 | 15.70 | 15.75 | -0.05 |
|      | 5     | 14.70 | 14.70 | 0.00  | 15.00 | 15.05 | -0.05 | 15.70 | 15.75 | -0.05 | 21.20 | 21.20 | 0.00  | 20.10 | 20.13 | -0.03 | 21.10 | 21.13 | -0.03 |
|      | 6     | 25.80 | 25.81 | -0.01 | 23.70 | 23.75 | -0.05 | 24.70 | 24.74 | -0.04 | 27.20 | 27.22 | -0.02 | 25.50 | 25.59 | -0.09 | 26.30 | 26.32 | -0.02 |
|      | 7     | 24.60 | 24.62 | -0.02 | 22.30 | 22.40 | -0.10 | 23.00 | 23.03 | -0.03 | 24.60 | 24.62 | -0.02 | 22.30 | 22.40 | -0.10 | 23.00 | 23.03 | -0.03 |
|      | 8     | 19.10 | 19.12 | -0.02 | 17.00 | 17.06 | -0.06 | 17.60 | 17.61 | -0.01 | 13.80 | 13.81 | -0.01 | 9.60  | 9.63  | -0.03 | 12.90 | 12.93 | -0.03 |
|      | 9     | 5.70  | 5.72  | -0.02 | 1.20  | 1.23  | -0.03 | 5.20  | 5.22  | -0.02 | 13.80 | 13.81 | -0.01 | 9.60  | 9.63  | -0.03 | 12.90 | 12.93 | -0.03 |

In sum, $\bar{T}_4$ is slightly less than $\bar{T}_{24}$, the difference between them is not too much. The influence on data statistics and statistical data accuracy is very small, which does not affect the data representation. In the study of the long time series, the two results can be replaced with each other.

### 4. Interannual variation trend and preliminary quantitative estimation of SST and SAT

In order to reveal the long-term trend of SST and SAT in the Bohai sea area, and to give a preliminary quantitative estimation of the annual change of them, this paper adopts the linear trend estimation method to study SST and SAT[16]. $X_i$ is used to represent a hydrometeorological variable with sample size $n$, and $t_i$ is the time corresponding to $X_i$. The linear regression equation between $X_i$ and $t_i$ is established: $X_i = a + bt_i$ ($i = 1, 2, ..., N$), this formula can be seen as a special, and the simplest form of linear regression. The meaning of it is to express the relationship between $X$ and time $t$ with a reasonable straight line. In this method, $B$ is the regression coefficient. Its sign indicates the trend of climate variables $X$, and its size reflects the rate of $X$ rise or fall, which indicates the change rate of the research variables.
The annual average values of SST and SAT in Bohai sea area, the regression lines and equations are shown in Figure 2- Figure 3. The red curve represents the average value of 11-point slide, which reflects the interannual variation. It shows clearly in Figure 2 that the SST annual change of the 6 oceanic stations is slightly different in the past 53 years, but the upward trend is obvious. The trend of change is highly consistent with the interdecadal variation trend. The average SST annual variation of these 6 stations can be roughly calculated as an increase of 0.53°C for 53 years with an average annual increase of 0.010°C.

Figure 2. Yearly mean average and regression line and equation of SST in Bohai seas

Figure 3. Yearly mean average and regression line and equation of SST and SAT in Bohai Sea

Figure 3 shows the annual average of SST and SAT (mean SST and SAT averaged over 6 stations) in the Bohai Sea and the regression lines. It can be seen from the Figure 3 that SAT, like SST, has an increasing trend in the past 50 years. The annual rate of SAT (0.043°C/a) is much larger than that of SST (0.010°C/a). The former is 4.3 times of the latter. It indicates that the meteorological elements are more sensitive to the changes of environmental conditions than the hydrological elements. The phenomenon of atmospheric warming in the Bohai Sea is very significant.

In order to furtherly understand the long-term significant trends and persistent changes of SST and SAT, this paper uses the method of cumulative anomaly curve to study and analyze. Cumulative
anomaly is a commonly used method to determine the trend of change from the curve. Figure 4 is the cumulative anomaly curves of the 6 oceanic stations SST in the Bohai sea area. Although the curves of each station have obvious ups and downs, it can be clearly diagnosed that the trend of the SST of each station occurred a significant mutation around 1987.

![Cumulative anomaly curve of SST in Bohai Sea](image1)

**Figure 4.** Cumulative anomaly curve of SST in Bohai Sea

The cumulative anomaly values of SST and SAT in the Bohai sea area are plotted as shown in Figure 5. Although the cumulative anomaly values of SST are negative, most of the curves show that the SST of Bohai sea experienced a significant fluctuation in the past 53 years. From 1960 to 1987, SST had a downward trend, and began to increase after 1987, the upward trend has not been reduced until 2009. The trend of the cumulative anomaly curve of SAT is consistent with SST.

![Cumulative anomaly curve of SST and SAT in Bohai Sea](image2)

**Figure 5.** Cumulative anomaly curve of SST and SAT in Bohai Sea

5. **Conclusions**

- The results of the measured SST data at different observing frequency of the oceanic station in the Bohai sea area show that 3 moments daily average SST is slightly lower than 24 moments daily average SST. There is a little difference between them. The gap is generally less than 0.10°C. The monthly average SST difference is in 0.05°C or less. The influence of 3 moments daily average SST of data statistics and statistical data accuracy is very small, which does not affect the data representation. It can be used to study the long time series problem.

- In the past 50 years, the marine environmental conditions in the Bohai sea area have changed significantly. The sea surface temperature and sea surface air temperature have increased significantly. The sea surface air temperature is more obvious. The phenomenon of atmospheric warming is significant. The annual variation rate of SAT was 0.043°C/a, which increased by 2.06°C in the past 48 years. The annual variation rate of SST was 0.010°C/a,
which increased by 0.53 °C in the past 53 years. Although the long-term trend of these two factors is significantly increased, but there was a significant mutation around 1987. From 1960 to 1987, it had a downward trend, after 1987 it began to grow, the upward trend has not diminished until 2009.

- By using the oceanic stations observation data, the quantitative estimate of the long-term trend of the hydrological and meteorological factors in Bohai sea area during the past 50 years is very useful and important for us to understand the long-term trend and mechanism of Chinese coastal environmental status in recent years. This is not only the key of the scientific development of their own needs, but also the key to sustainable utilization of Chinese marine resources.

References

[1] Feng Shizuo, Li Fengqi, Li Shaojing 2003 Introduction to Marine Science [M]. Beijing: Higher education press 434.

[2] Lin Chuanlan, Su Jilan, Xu Bingrong, et al. 2001 Long-term variations of temperature and salinity of the Bohai Sea and their influence on its ecosystem Progress in Oceanography 49 7-19.

[3] Fang Guohong, Wang Kai, Guo Fengyi, et al. 2002 Long-term changes and inter relations of annual variations of the hydrographical and meteorological parameters of the Bohai Sea during recent 30 years Oceanologia et Limnologia Sinica 33(5) 515-525.

[4] Bai Hong, Hu Dunxin, Chen yongli, et al. 2004 Statistic characteristics of thermal structure in the southern Yellow Sea in summer Chinese Journal of Oceanology and Limnology 22(3) 237-243.

[5] Huo Wenfeng, Zhang Aijun, Zhang Shudong 1996 Decadal and pentadal distribution of number of stations for temperature and salinity observation in Bohai Sea, Yellow Sea and East China Sea Marine Science Bulletin 15(1) 67-77.

[6] Intergovernmental Panel on Climate Change 2014 Working Group II. Climate Change 2014: Impacts, Adaptation, and Vulnerability[M]. New York: Cambridge University Press 411-484.

[7] Ji Shijian, Zhou Weifeng, Fan Wei, et al. 2016 Sea surface temperature anomaly’s interannual variability in pelagic fishing grounds of China Marine Sciences, 49(1) 85-93.

[8] Ma Chao, Hu Xia, Wu Dexing, et al. 2010 The spatial distribution and temporal evolution of salinity at the sections and observation stations in the Yellow Sea and Bohai Sea Marine Sciences 34(9) 70-81.

[9] Ma Chao, Wu Dexing, Lin Xiaopei 2006 The characters of interannual and long-term variations of salinity in the Bohai Sea and Yellow Seas Periodical of Ocean University of China 36(6) 7-12.

[10] Wu Dexing, Mu Lin, Li Qiang, et al. 2004 Long-term varitation characteristics and possible dominant factors of salinity in Bohai Sea Progress in natural science 14(2) 191-195.

[11] Xia Huayong, Gu Wancai 2008 Statistical analysis of mean sea temperatures at tidal gauge station along Guangxi coast Marine Science Bulletin 19(4) 15-21.

[12] Diao Xuexian 1996 Statistical analysis of mean sea surface temperatures in Shijiu port Marine Science Bulletin 15(6) 15-19.

[13] Wang Lina, Chen Xiaohong, Li Yuean, et al. 2009 Heuristic segmentation method for changepoint analysis of hydrological time series Yangtze River 40(9) 15-17.

[14] State Technical Supervision Bureau of the people’s Republic of China. GB/T 14914-1994. The specification for offshore observations[S]. Beijing: Standards Press of China, 1994: 6.

[15] State Technical Supervision Bureau of the people’s Republic of China. GB/T 14914-2006. The specification for offshore observations[S]. Beijing: Standards Press of China,2006: 6, 79.

[16] Wei Fengying 1999 Statistical diagnosis and prediction technology of modern climate[M]. Beijing: China Meteorological Press 82-122.