Buoy observation data verification and application

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Abstract. The buoy automatic observation is greatly influenced by the marine environment. The quality of buoy observation data needs to be tested before it is applied. In this paper, buoy observation data is verified with the ocean station and ocean section observation data, and the reliability of buoy observation is analyzed. On this basis, the hydrometeorological condition in the central Bohai Sea is analyzed for surface water temperature, surface salinity, sea surface air temperature and sea surface pressure. The results show: The reliability and continuity of buoy observation of sea surface water temperature, sea surface air temperature and sea surface pressure are high; the reliability of sea surface salinity, average wind speed, average wind direction, significant wave height, significant wave period, average wave height and average wave period are low. The hydrometeorological condition in the central Bohai Sea analyzed by buoy observation data is basically consistent with the existing research conclusions. The lowest water temperature in the central Bohai Sea occurs in February.

1. Foreword
Ocean buoy is an important technical equipment for fixed-point observation of the marine environment, which is distributed in specific sea area. It can collect and transmit the fixed-point marine environmental observation data for a long time continuously and automatically. It is an important part of the modern marine environmental stereoscopic observation system [1][2]. Ocean station observation, which covers the coastal waters of our country in space, carries out fixed-point, long-term and continuous observation activities for marine hydrology, marine meteorology and other elements, is one of the mature and stable observation methods at present. Ocean Section survey is an observation activity carried out at a site on a specific cross-section.

At present, buoy, ocean station and ocean section observations are three conventional observation methods of offshore hydrometeorological observations in China. But these three observation methods have their own characteristic. Both ocean buoy and ocean station can make fixed-point, long-term and continuous observations on fixed stations in specific sea area. After long-term stable operation, ocean station observation has formed a relatively perfect operation system to ensure the reliability of data. In addition, the offshore station is located near the coast, which is convenient for observers to maintain, so the data has high quality; while the ocean buoy is generally located in the offshore sea water at a distance, which is relatively inconvenient to maintain. Some of these buoys operate continuously for many years, some parameters may drift. Affected by the complex marine environment, includes current, wave, shipping, biological attachment and other factors, the uncertainty of the quality of buoy automatic observation data is greatly increased [3]. Ocean section data is relayed on ship surveying and manual operation, the quality of the ocean station data is relatively reliable, but it has the characteristic of time discontinuity, the ocean section data can only reflect the change characteristics...
of the survey period. This paper compares the observation data of ocean stations and section stations with those of buoys whose quality is relatively uncertain, in order to verify the quality of buoy observation data and determine which parameters are more reliable for buoy observation. On the basis of determining the reliable quality of buoy observation elements, the hydrometeorological condition of the central Bohai Sea are analyzed by using one year observation data of five buoy stations in the central Bohai Sea and the observation data of an adjacent ocean stations for one year.

2. Data information
The buoy data is hourly from January to December 2016. The observation sea area is the Bohai Sea. There are five stations, including B1 in Laizhou Bay Estuary, B2 in Liaodong Bay Estuary, B3 and B4 in the central part of the Bohai Sea, B5 in the Bohai Strait, which are all large (10m) anchored buoys. Observation elements include surface water temperature, surface salinity, average wind speed, average wind direction, sea surface air temperature, sea surface pressure, significant wave height, significant wave period, average wave height, average wave period, 1/10 wave height, 1/10 wave period, maximum wave height, maximum wave period, comprehensive wave direction, etc.

The data of S1 ocean station is hourly from January to December 2016. The observation elements include surface water temperature, surface salinity, average wind speed, average wind direction, sea surface air temperature, sea surface pressure, significant wave height, significant wave period, average wave height, average wave period, 1/10 wave height and 1/10 wave period, etc.

The data of marine section survey (C1) is the data of February, May, August and December 2016, using surface water temperature and surface salinity data.

The meteorological data measured by the buoy are from the wind speed and direction sensor which is about 8 meters away from the sea surface, and the temperature and salinity data are 1-2 meters underwater. The wind speed and direction data measured by the ocean station are from the XFY3-1 wind speed and direction sensor about 11 meters high from the ground, the air pressure sensor is 1.5 meters high from the ground, and the temperature and salinity data are from YZY4-3 temperature and salinity sensor which is 0.5 meters underwater.

![Figure 1. Position map of buoy, ocean station and ocean section stations. depth unit: m.](image-url)
The data stations are shown in Figure 1. From the station map, it can be seen that both S1 and B5 stations are located in the Bohai Strait, which are close to each other and have the same water depth. From the aspect of water mass analysis, both of them are located in the Bohai-Yellow Sea mixed water mass in summer, and both of them are in the Yellow Sea mixed water mass in winter, with the same characteristics. C1 station is adjacent to B3 station. Therefore, S1 station data and B5 station data are used to compare, C1 station data and B3 station data are used to compare.

3. Processing methods
In order to compare the observation data of buoy and ocean station, we first make a comparison between the measured value of buoy and ocean station. At the same time, we consider four statistics, average error, relative error, root mean square error and correlation coefficient to compare. The calculation formulas are as follows[4]. Because the section observation data are discrete and the amount of data is small, we only consider the comparison of the measured value of buoy and section observation data.

\[
\text{average error} = \overline{|Y_i - X_i|}
\]
\[
\text{relative error} = \left(\frac{|\overline{Y} - \overline{X}|}{\overline{X}}\right) \times 100\% \tag{2}
\]
\[
\text{Root mean square error} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (Y_i - X_i)^2} \tag{3}
\]
\[
\text{correlation coefficient} = \frac{\overline{X_i Y_i}}{\sigma_x \sigma_y} - \frac{\overline{X_i - \overline{X}}(Y_i - \overline{Y})}{\sigma_x \sigma_y} \tag{4}
\]

Among them: \(X_i\) representing the time series of ocean station data, \(Y_i\) representing the time series of buoy data, overline representing the average value, "\(|\cdot|\)" representing the absolute value, \(\sigma\) representing the mean square deviation.

4. Result analysis

4.1. Comparison and analysis of buoy and ocean station observation data

| Parameter/statistic         | Average error | Relative error(%) | Root mean square error(%) | Correlation coefficient |
|-----------------------------|---------------|-------------------|---------------------------|------------------------|
| Surface water temperature   | 0.93°C        | 7.55              | 1.84                      | 0.98                   |
| Surface salinity            | 0.37          | 1.18              | 0.42                      | 0.44                   |
| Sea surface air temperature | -0.91°C       | -7.09             | 6.4                       | 0.81                   |
| Sea surface pressure        | 3.8hpa        | 0.38              | 3.9                       | 0.90                   |
| Average wind speed          | 0.14m/s       | 2.91              | 2.62                      | 0.68                   |
| Average wind direction      | -8.94°        | -4.64             | 119.23                    | 0.42                   |
| Significant wave height     | -0.17m        | -21.75            | 0.75                      | 0.20                   |
| Significant wave period     | -0.11s        | -2.49             | 1.40                      | 0.14                   |
| Average wave height         | -0.11m        | -20.83            | 0.49                      | 0.20                   |
| Average wave period         | 0.75s         | 20.87             | 1.99                      | 0.16                   |
Table 1 gives the values of average error, relative error, root mean square error and correlation coefficient between buoy and ocean station elements. From table 1, we can see that there is average error in the mean value of each element between buoy and ocean station. The reason is analyzed, which is related to the incomplete coincidence of their geographical locations and the influence of their geographical locations. The correlation coefficient of surface water temperature, sea surface air temperature, sea surface pressure and average wind speed is higher, while the correlation of other factors such as surface salinity, average wind direction, significant wave height/period, average wave height/period is lower. We also draw the time series comparison chart of buoy and ocean station elements, and analyze it in combination with Table 1, specifically according to the elements as follows.

(1) Sea surface temperature

Figure 2 is the time series (subtracting mean value) comparison chart of surface water temperature between B5 buoy and S1 ocean station from January to December 2016. It can be seen from the chart that the change trend is basically the same, and the correlation coefficient is 98% from Table 1 which is very high. The change range of both is consistent, the change range of surface temperature in winter and spring is small, and in summer and autumn is large. The average annual value of buoy is 0.93 °C higher than that of the ocean station.

![Figure 2](image)

**Figure 2.** Time series (subtracting mean value) comparison of sea surface temperature between B5 and S1 from January to December 2016.

(2) Surface salinity

From the comparison of B5 buoy and S1 ocean station surface salinity time series (subtracting mean value) from January to December 2016 (Figure 3), we can see that the overall change trend of surface salinity of B5 buoy and S1 ocean station is basically the same from January to September, but there is a numerical deviation. Since September, the salinity of ocean station has increased greatly. After checking the logs of ocean station, it is found that S1 ocean station replaced the salinity sensor in September. After replacing the sensor, the variation trend of buoy and ocean stations is consistent, and the average error is smaller. However, the difference between the buoy and the ocean station has increased again since December. Overall, the correlation of surface salinity between buoy and ocean station is relatively poor. The reason is that the salinity sensors of ocean station and buoy are seriously affected by biological attachment, resulting in inaccurate salinity measurement. It is obvious from the ocean station that the salinity data increased greatly after the replacement of the salinity sensor in September.
(3) Sea surface temperature and air pressure

By comparing the time series (subtracting mean value) of sea surface air temperature and sea surface pressure in Figure 4 and Figure 5, it can be seen that the correlation between sea surface air temperature and sea surface pressure at B5 buoy and S1 ocean station is very good. Both of them have high consistency in terms of change trend and range. From Table 1, the correlation coefficient of sea surface air temperature between B5 buoy and S1 ocean station is 0.81, and the correlation coefficient of pressure between them is 0.90. Buoy observations have high reliability in monitoring sea surface air temperature and air pressure.

(4) Other elements

Other elements such as average wind speed, average wind direction, significant wave height, significant wave period, average wave height, average wave period, the correlation between buoy observation data and ocean station observation data is not high.

4.2 Comparative analysis of buoy and ocean section data

Figure 6 is a comparison of surface water temperature between B3 buoy and C1 ocean section station in 2016. Figure 7 is a comparison of surface salinity measured at two stations in February, May, August and November. The comparison value is B3 value minus S1 value. It can be seen that the surface water temperature surveyed in February, May, August and November of the section basically
coincides with the surface water temperature observed by buoy. The maximum deviation between these two is 0.36 ℃, which appears in May. It is shown that both of them have high reliability in surface water temperature observation.

From the comparison map of sea surface salinity measured in February, May, August and November at two stations in Figure 7, it can be seen that the salinity observed by B3 buoy in February and May is obviously smaller than that observed by ocean section, The salinity observed by B3 buoy in August is close to that of ocean section, and the observation values are the same in November. The maximum deviation between them is 0.56, which appears in February. It is shown that the buoy observation has a certain deviation for the observation of salinity.

5. Analysis of hydrometeorological condition in the central Bohai Sea
The reliability of buoy observation is confirmed by comparing and analyzing the observation data of buoy, ocean station and section station. Five buoys in the central Bohai Sea and S1 ocean station data are used to analyze the distribution and seasonal variation of sea surface temperature, sea surface salinity, sea surface air temperature and sea surface pressure.

From the monthly average change chart of surface water temperature of each station in Figure 8, it can be seen that the highest surface water temperature of each station all occurs in August and lowest value all occurs in February, which is different from the conclusion that ‘the water temperature in January is lower than that in February’[5][6]. The reason is that the coastal water of Bohai Sea is shallow and the response to air temperature is fast, so the water temperature in January is higher than that in February, while the water depth in the central part is deepened, so the response time is longer, and the lowest water temperature occurs in February. The annual variation of surface water temperature in the central Bohai Sea ranges from 18.53 to 25.46 degrees centigrade (Table 2). In winter, the water temperatures of B5, S1 in the Bohai Strait and B4 in the central Bohai Sea is significantly higher than that in the Laizhou Bay Estuary (B1), Liaodong Bay Estuary (B2) and B3 in the central Bohai Sea. It is verified that a high temperature tongue extends from the North Yellow Sea to the West through the Bohai Strait into the Bohai Sea[7]. In spring, the surface water temperature begins to increase significantly, the surface high temperature tongue and low temperature phenomena along the Bohai Sea costal disappears, which results in the phenomenon of high water temperature along the Bohai Sea coast and low water temperature near the central and Strait[7]. From the graph, it can be seen that the surface water temperature of B1 and B2 is higher than that of buoys in the central Bohai Sea and the Bohai Strait, among which the water temperature of Laizhou Bay estuary is higher than that of Liaodong Bay estuary, and that of Bohai Strait is the lowest. In summer, the surface water temperature of the Bohai Sea continues to rise to the highest level in the whole year and distributes evenly, the water temperature along the coast is still higher than that near the central and the strait. In autumn, the surface water temperature of the Bohai Sea declines significantly. In September and early
October, the coastal water temperature is still higher than that of the central part of the Bohai Sea and the Bohai Strait. In mid-and late October, it begins to change to the winter type, the coastal water temperature is low and the central water temperature is high.

From the monthly average change chart of surface salinity of each station in Figure 9, it can be seen that most stations are in the period of decreasing salinity from April to September and increasing salinity from October to March. During the year, the highest surface salinity appears in March or April, and the lowest surface salinity appears in August. From Table 2 the annual variation of surface salinity in the central Bohai Sea ranges from 0.86 to 1.55. In winter, the surface salinity of the Bohai Sea keeps rising; the distribution of surface salinity in the Bohai Sea corresponds to the distribution of surface water temperature. The salinity of B5 and S1 in the Bohai Strait and B4 in the central part of the Bohai Sea are also higher than that in the other three buoy stations. In spring, salinity begins to decline after rising to the highest value, and the salinity of B5, S1 and B4 are still higher than the other three stations. In summer, the salinity of the Bohai Sea decreases rapidly, because this season has the largest rainfall and continental runoff in the whole year. In autumn, the salinity begins to rise, and the salinity distribution of each station is much more uniform, with little difference.

From Figure 10, the highest sea surface air temperatures of all stations occurs in August and and lowest occurs in January. There is little difference among stations. From Figure 11, the annual variation of sea surface temperature in the central Bohai Sea ranges from 26.49 to 27.23 degrees centigrade. The maximum air pressure appears in January and the minimum value appears in July, and the difference among stations is small. The annual variation of sea surface pressure in the central Bohai Sea ranges from 21.74 to 24.04 hPa.
Table 2. Annual range of parameters in central Bohai Sea.

| buoy | Sea surface temperature(℃) | Surface salinity | Sea surface air temperature(℃) | Sea surface pressure(hpa) |
|------|-----------------------------|------------------|-------------------------------|--------------------------|
| B1   | 25.38                       | --               | 27.23                         | 24.04                    |
| B2   | 23.30                       | 1.02             | 29.01                         | 23.17                    |
| B5   | 21.55                       | 0.99             | 26.49                         | 22.57                    |
| B3   | 25.46                       | 0.86             | 28.00                         | 23.78                    |
| B4   | 21.77                       | --               | 27.19                         | 21.74                    |
| S1   | 18.53                       | 1.55             | 27.06                         | 22.47                    |

6. Conclusion and discussion

In this paper, the observation data of buoy, ocean station and ocean section are compared, and the reliability of buoy observation is analyzed. On this basis, the hydrometeorological condition in the central Bohai Sea is analyzed for surface water temperature, surface salinity, sea surface air temperature and sea surface pressure. The following conclusions are drawn:

1) The reliability and continuity of buoy observation of sea surface water temperature, sea surface air temperature and sea surface pressure are high; the reliability of sea surface salinity, average wind speed, average wind direction, significant wave height, significant wave period, average wave height and average wave period are low. Through the comparison and analysis with the observation data of ocean station, the correlation between buoy observation of sea surface temperature, sea surface temperature and sea surface pressure and the observation of ocean stations is good, but the correlation of sea surface salinity is poor. The correlation of other factors is poor. Compared with ocean the section data, it is found that the buoy observation of sea surface temperature is reliable, and the difference of sea surface salinity with ocean section observation is large.

2) The hydrometeorological condition in the central Bohai Sea analyzed by buoy observation data are basically consistent with the existing research conclusions. The lowest water temperature in the central Bohai Sea occurs in February.

3) China's buoy observation has been running continuously for many years. The next step is to collect long-term buoy observation data to analyze and study the hydrometeorological condition in the national sea area.

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