Research on the characteristics of wave observation of wave glider

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Abstract. Wave glider is a new class of ocean mobile observation vehicle. It is a new applied research direction that using wave glider for wave observation. Currently, wave observation is usually performed at fixed points by using wave buoys, the research on using wave glider for navigational observations is still rare, and the characteristics of wave observation using wave glider is not yet mastered. The article Research on the characteristics of wave observation of wave glider, Based on the experimental results, analyze the differences and the correlations between wave glider and wave buoy in wave height, wave period, wave number and wave direction. Analyze the existence mechanism of the difference and propose the theoretical basis for eliminating the difference or correcting the observation data of wave glider. Based on experimental data and theoretical analysis, it is proved that the wave glider is feasible to observe wave. The average correlation coefficient between the observation data of wave glider and the observation data of wave buoy is above 0.9, the results prove that there is a strong correlation between wave glider and wave buoy.

1. Introduction

Wave glider is a new class of ocean mobile observation vehicle that using wave power to advance and using solar power to support instrument communication, navigation and sensor data acquisition [1-3], shown in Fig.1. Wave Glider harvests abundant natural energy from ocean waves, providing a persistent ocean presence for detailed ocean observation and studies on persistent robotic control. This platform has a demonstrated endurance exceeding one year, and offers a unique platform for ongoing engineering development and a range of new applications for robotics research and ocean scientists alike. It can be equipped with a variety of sensors for real-time monitoring, such as wind, humidity, temperature, air pressure and sea surface temperature, salinity and flow rate. It can also be equipped with active and passive sonar to observe the background noise of the marine environment and carry water quality sensor to observe dissolved oxygen, chlorophyll, pH and turbidity, etc. It can carry out long-term online monitoring and early warning of natural disasters such as red tides, green tides and water pollution [4-6].
Currently, wave observation is usually performed at fixed points by using wave buoys, typical wave buoy shown in Fig.2. Wave buoys refer to the anchor buoy placed on the surface of the water and fluctuating up and down with the wave. The acceleration sensor or gravity sensor is installed inside of the buoy to collect the motion parameters of the buoy changing with the sea surface fluctuation, and then calculates the characteristic parameter of wave [7, 8]. Typical wave buoys are “wave rider” developed in Netherlands [9, 10] and “Triaxys” developed in Canada [11]. In addition, many research institutes have also developed this kind of wave buoy, such as the national ocean technology center, Ocean University of China, etc.

However, there are few studies on wave observation using mobile observation platforms such as wave glider [12, 13], and there are relatively few literatures on using wave glider to observe wave. In previous research, M [14] carried out research on wave height determination with a GPS wave glider in Loch Ness, but lacked relevant research on wave number, wave direction and wave period. Phillip Ngo [15, 16] carried out the research on the correspondence between wave height and wave glider speed, but did not research the authenticity of the observation of wave characteristic data. This paper analyzes the characteristics of wave observation using wave gliders, and designed a comparison experiment for
compare the observation data of the wave glider with the observation data of the wave buoy, analyzes the correlation, difference and average difference, and to verify the feasibility of wave observation using wave glider.

2. Experiment design

2.1. Principle of wave observation using wave glider
The wave glider is composed of a two-part architecture, a boat-shaped float and a submerged glider and the armored cable by a tether approximately 7 m long. The wave glider design mechanically converts energy from ocean waves in order to provide essentially limitless propulsion. The boat-shaped float floating on the surface of the water, which can oscillate up and down with the waves, and the submerged glider is suspended under the water. Based on the characteristics of wave glider oscillating up and down with waves, the wave can be observed by installing wave sensors on the boat-shaped floating body.

2.2. Experiment design
In order to ensure the consistency of the observation data, the design of this comparative experiment follows the following principles:

1. Same sensor: same model, same observation accuracy and range;
2. Same position: The path of wave glider should be as close as possible to the anchor position of the wave buoy;
3. Same time: The wave glider and the wave buoy should observe the waves at the same time;

In order to ensure the validity of the comparison data, the wave glider and the wave buoy are equipped with the same wave sensor, and the measurement range and accuracy are consistent. Due to the difference working mode between wave glider and wave buoy, wave glider moves in a circular motion of small radius around the anchor point of the wave buoy. This is done to ensure that the observation position and the parameters of the marine environment are approximately the same. This experiment was carried out near the Qianliyan island, the path of the wave glider is a circle around the wave buoy, and the center of the circle is the anchor point of the wave buoy and the radius is 5km. The path setting is shown in Fig.3.

![Fig. 3. Experiment area and path planning of wave glider.](image-url)
3. Data analysis

The wave glider carried out a 24-day experiment around the wave buoy, intercepting the data of 10 consecutive days for data quality comparison of wave height, wave period, wave direction and wave number, and the wave glider and wave buoy Correlation analysis was performed.

3.1. Wave height analysis

3.1.1. Correlation analysis. The wave height (WH) data include the maximum wave height (MWH), the one-tenth wave height (OTWH), the effective wave height (EWH) and the average wave height (AWH). Plot the curve of wave height observed by the wave glider and by the wave buoy, as shown in Fig.4. Then draw contrast curves for MWH, OTWH, EWH, AWH, and draw the correlation distribution diagrams of the four types of wave heights, as shown in Fig.5-8. Analyze the comparison curve of Fig. 4. The wave height distribution of the wave glider has the same general trend as the wave height distribution of the wave buoy. But, the wave height observed by the wave glider before and after the 1.5th and 8th days is quite different from the wave height observed by the wave buoy, and the wave height is relatively larger on 8th day. From the results of Figure 5-8, the correlation coefficients of the four wave heights are 0.85, 0.92, 0.94, 0.94, the average correlation coefficient is 0.903. The MWH correlation coefficient is smallest, only 0.85, and the MWH curve has a small degree of coincidence. The correlation coefficient of AWH and the EWH are largest, reaching 0.94, and the coincidence degree of the AWH curve is highest. The magnitude relationship of the correlation coefficient is the MWH < TWH < EWH ≦ AWH. The maximum difference of wave height is the MWH, the maximum difference is 0.74m, and the average of absolute difference is only 0.15m. The minimum difference of wave height is the AWH, the maximum difference is 0.3214m, the average of absolute difference is 0.04m, and the maximum difference of the four types of wave height appear at the same time. Some characteristic parameters of wave height are shown in Tab.1.

The above analysis results prove that there is a strong correlation between the wave glider and the wave buoy for the observation of wave height, and it also shows that wave glider has a certain weakening effect on the observation of wave height, but the average effect of long-term is small.

![Fig. 4. Wave height comparison curve.](image)
Fig 5. MWH contrast curve and correlation distribution diagram.
Fig 6. OTWH contrast curve and correlation distribution diagram.
Fig 7. EWH contrast curve and correlation distribution diagram.

EWH Contrast Curve / Correlation coefficient: 0.9398

Difference Curve Wave Wuoy - Wave Wlider

Wave Wlider Wave Wuoy

EWH Correlation Distribution

R = 0.9398
Fig 8. AWH contrast curve and correlation distribution diagram.

Table 1. Wave height parameters.

|        | correlation coefficient | average value | Maximum difference /m | average of absolute difference /m |
|--------|-------------------------|---------------|------------------------|-----------------------------------|
|        |                         | Wave Buoy     | Wave Glider            |                                   |
| MWH    | 0.85                    | 1.14          | 1.13                   | 0.74                              | 0.1472                           |
| TWH    | 0.92                    | 0.88          | 0.93                   | 0.63                              | 0.0891                           |
| EWH    | 0.94                    | 0.70          | 0.74                   | 0.49                              | 0.066                            |
| AWH    | 0.94                    | 0.44          | 0.48                   | 0.32                              | 0.0425                           |
| average value | 0.903            | /             | /                      | 0.545                             | 0.093                            |
3.1.2. Difference analysis. Further analyze the average value of the four types of wave heights, except for the MWH, the average value of the wave height observed by wave glider is larger than by wave buoy, the average difference is about 4 cm. Since the wave sensor of the wave glider is installed slightly behind, the position diagram of the wave sensor is shown in the Fig.9 (a).

![Wave sensor installation position and height change](image)

When the boat-shaped float of the wave glider oscillates up and down with the wave, the boat-shaped float will have an inclination angle of 5 to 10 degrees, which causes the position of the wave sensor to rise and fall for a small distance. In turn, the observation value of the wave height using wave glider is increased. When the wave glider is moving up in the trough, the position of the wave sensor is further drop a certain distance due to the pitch of the body, and when the wave glider is moving down in the crest, the position of the wave sensor is further rise a certain distance due to the pitch of the body. For example, when the wave glider is in a trough, the position of the wave sensor changes as shown in Fig.9(b), the change value of the wave sensor is $\Delta H$. The error in observation of wave height include two parts: from trough to peak and from peak to trough. Therefore, the value change in wave height can be expressed as $\Delta H = 2 \Delta H = 2 \Delta H = 2 H_w (\cos \theta - \cos \theta)$.

Where, $H_w$ and $L_w$ represent the height of the wave sensor from the water surface and the longitudinal displacement of the wave sensor from the center position.

The analysis of the four types of wave heights shows there is a strong correlation between the wave glider and the wave buoy for the observation of wave height, indicating that the wave glider has a good wave-like property and can reflect the wave height value more realistically. But it has a certain weakening effect on the larger wave height, when the wave height is small, the wave height observed by the wave glider is slightly higher than the true value due to the position of the wave sensor is not in the center.

3.2. Wave period analysis

The wave period (WP) includes the maximum wave period (MWP), the one-tenth wave period (OTWP), the effective wave period (EWP), and the average wave period (AWP). The wave period data observed by the wave buoy and the wave glider are plotted as shown in Fig. 10. Then draw contrast curves for MWP, OTWP, EWP, AWP, and draw the correlation distribution diagrams of the four types of wave periods, as shown in Fig.11-14. It can be seen from the curve of WP, the wave period observed by the wave glider has the same distribution trend as the wave period observed by the wave buoy. But, in the beginning, the difference of the MWP is large. Analyze the comparison curve of fig5-8, the correlation coefficients of the four types of wave periods are 0.78, 0.94, 0.94, 0.96, the average of the correlation
coefficients is 0.905, the correlation coefficient of MWP is smallest, only 0.78, the coincidence degree of the curve is small, and the correlation coefficient of the AWP is largest, up to 0.96, the AWP curve of wave glider has a high degree of coincidence with the AWP curve of wave buoy. The relationship between the correlation coefficients is MWP < TWP < EWP ≦ AWP, which has the same correlation distribution with the wave height, the correlation coefficient of the maximum value is the smallest, and the correlation coefficient of the average value is the highest. In addition, the maximum difference of MWP is the largest, which is 5.84 s, the average of absolute difference is 0.83 s; the maximum difference of AWP is the smallest, which is 1.25 s, and the average absolute difference is only 0.3 s. Some characteristic parameters of wave period are shown in Tab. 2.

The above analysis results prove that there is a strong correlation between the wave glider and the wave buoy for the observation of wave period, and it also shows that wave gliders have also an effect on the wave period while affecting the wave height.

Fig 10. Wave period comparison curve.
Fig 11. MWP contrast curve and correlation distribution diagram.

R = 0.7782
**Fig 12.** OTWP contrast curve and correlation distribution diagram.
Fig 13. EWP contrast curve and correlation distribution diagram.
Fig 14. AWP contrast curve and correlation distribution diagram.

Table 2. Wave period parameters.

| Wave Buoy | Wave Glider | Maximum difference /s | average of absolute difference /s |
|-----------|-------------|-------------------------|-----------------------------------|
| MWP       | 0.78        | 7.31                    | 7.08                              | 5.84 | 0.83 |
| OTWP      | 0.94        | 7.22                    | 7.15                              | 2.39 | 0.42 |
| EWP       | 0.94        | 5.72                    | 5.69                              | 2.24 | 0.32 |
| AWP       | 0.96        | 7.04                    | 6.99                              | 1.25 | 0.3  |
| average   | 0.905       |                         |                                   | 2.93 | 0.468 |

average of absolute difference /s
3.3. Wave number analysis

Draw the contrast curve of wave numbers (WN) observed by the wave glider and wave buoy, and draw the correlation distribution diagrams of the wave numbers, as shown in Fig. 15. It can be seen from the curve of WP, the wave numbers observed by the wave glider has the same distribution trend as the wave period observed by the wave buoy, and the correlation coefficient is about 0.95. The maximum difference of wave numbers is 39, the average of absolute difference is 9.09, the average wave numbers observed by wave buoy is 184.25, and the average wave numbers observed by wave glider is 184.66. Since the single wave period observed by the wave glider is slightly smaller than the single wave period observed by the wave buoy, the response speed of the wave glider is slightly faster than the wave buoy, resulting in the average wave numbers of the long-term observation of the wave glider is slightly more than the wave buoy, but the difference is only 0.41. Some characteristic parameters of wave period are shown in Tab. 3.

It can be seen from the analysis results that there is a strong correlation between the wave glider and the wave buoy for the observation of wave numbers. That is to say, the wave glider has a good wave-following effect on the wave period.

![Wave number comparison curve](image)

Fig 15. Wave number comparison curve.
Table 3. Wave number parameters.

| Wave number | Correlation coefficient | average value | Maximum difference | Average of absolute difference |
|-------------|-------------------------|---------------|--------------------|-------------------------------|
| Wave Buoy   | 0.95                    | 184.25        | 184.66             | 39                            | 9.09                         |
| Wave Glider |                         |               |                    |                               |

3.4. Wave direction analysis

Draw the wave direction (WD) curve of the wave glider and wave buoy, as shown in Fig.16. The wave direction observed by the wave buoy has been oscillating around 140 degrees, except for the 9th day. From the 9th day, when the wave direction changes greatly in a short time, the wave glider can observe its change more accurately. The wave direction observed by the wave glider fluctuates greatly in the wave direction of the wave buoy observation, and the correlation of the wave direction is high, about 0.89. The maximum difference of wave direction is 53.63, the average of absolute difference is 20.48, the average wave number observed by wave buoy is 143.87, and the average wave number observed by wave glider is 158.01. Because the wave glider has the ability to maintain course, it will generate a certain magnitude of acceleration in the direction of force when the glider is disturbed by the wave. Therefore, the observation of wave direction has a large deviation. In addition, when the current heading of the wave glider does not coincide with the desired heading, the impact of the rudder will cause the generated acceleration to deflect to the desired heading. Therefore, the wave direction observed by the wave glider is a superposition direction of the true wave direction and the direction of its own acceleration. Some characteristic parameters of wave direction are shown in Tab.4.

The above analysis results prove that there is a strong correlation between the wave glider and the wave buoy for the observation of wave height, but the observation of wave direction has some deviation. It also shows that using wave glider to observe wave direction has a good wave-like property, but due to the influence of its own heading and autonomous navigation, the wave direction observed by the wave glider has a certain angular deviation from the actual wave direction.
4. Conclusion

It can be seen from the above analysis results that the wave glider has good wave-following behavior, and it can well reflect the wave height, wave period, wave number and wave direction. The correlation with the standard wave buoy is higher; the average correlation coefficient of wave height is 0.903, the correlation coefficient between EWH and AWH is largest, reaching 0.94; the correlation coefficient of MWH is smallest, only 0.85; The average correlation coefficient of wave period is 0.905, and the AWP is largest, reaching 0.96; The MWP is smallest, only 0.78. The correlation coefficient of wave number is 0.95, and the correlation coefficient of wave direction is 0.89, but the deviation of wave direction is larger, the maximum difference up to 53.63 degrees, the wave direction data needs to be corrected by removing the magnitude and direction of the acceleration of the wave glider. Overall, wave gliders are feasible for wave observations. Some parameters of wave observed by wave glider are shown in Tab. 5.

| parameter | Wave Buoy | Wave Glider | Maximum difference /degree | Average difference /degree |
|-----------|-----------|-------------|-----------------------------|---------------------------|
| WH        |           |             |                             |                           |
| MWH       | 0.85      | 0.74        | 0.1472                      |                           |
| OTWH      | 0.92      | 0.63        | 0.0891                      |                           |
| EWH       | 0.94      | 0.49        | 0.066                       |                           |
| AWH       | 0.94      | 0.32        | 0.0425                      |                           |
| WP        |           |             |                             |                           |
| MWP       | 0.78      | 5.84        | 0.83                        |                           |
| OTWP      | 0.94      | 2.39        | 0.42                        |                           |
| EWP       | 0.94      | 2.24        | 0.32                        |                           |
| AWP       | 0.96      | 1.25        | 0.3                         |                           |
| WN        |           |             |                             |                           |
| 0.95      | 39        | 9.09        |                             |                           |
| WD        | 0.89      | 53.63       | 20.48                       |                           |
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