Abstract—In this paper, three algorithms are applied to extract the wind direction using a month HFSWR data in an experiment with a single radar system. The preliminary results show that the three algorithms can all eliminate the ambiguity of the wind direction. And the RMS error (RMSE) obtained by the angle comparison multi-beam (ACMB) algorithm is 24.80°, which is better than the others. We can obtain that the ACMB algorithm is best available for extracting wind direction using the data obtained by this experiment. However, for the other data with different conditions, whether this algorithm is the best needs further examination.

Keywords—High frequency surface wave radar (HFSWR), wind direction, ambiguity elimination

1 Introduction

High frequency surface wave radar (HFSWR) can be used to track the moving targets and monitor the ocean surface parameters such as currents, wave and wind field. Both theory simulations and experiments confirm that the ratio of spectral power density of the positive and negative Bragg peaks is highly sensitive to the wind direction and so this can be used to extract wind direction [1-4]. However, for the monostatic radar, there exists a directional ambiguity as the radar cannot tell if the wind is from the right of the radar beam or the left. To solve this problem, some methods are developed [2-5]. Heron & Rose [2] presented a multi-beam (MB) method which finds spreading parameter and wind directions from three radar beams. Wyatt [3] applied a maximum likelihood (ML) method to estimate short wave directions and spreading. These methods can solve the problem of wind direction ambiguity for the monostatic radar. Based on the work of Heron & Rose, we have developed an algorithm to eliminate the ambiguity which is applied by comparing the included angles between three adjacent radar beams and the wind direction [6], which can be called angle comparison multi-beam (ACMB) in here. And we improve on the multi-beam algorithm by using the least square principle to increase efficiency of calculation (LSMB). In this paper we evaluate the three algorithms ACMB, LSMB, ML, using a month data obtained in an experiment by means of a monostatic radar system, and the accuracy of wind direction measurements are explored.

2 Brief Description of Algorithm to Extract Wind Direction

The ratio of spectral power density of two Bragg peaks has been previously used to estimate the wind direction, the first-order cross section is given by Barrick [7]

$$\frac{\sigma_i(\omega_B)}{\sigma_i(-\omega_B)} = \frac{S(-\vec{k}_0)}{S(2\vec{k}_0)}$$

(1)

where $\omega$ is the Doppler frequency, $\omega_B$ is the first-order Bragg frequency, $m=\pm 1$ denotes the sign of the Doppler shift, $\vec{k}_0$ is the radar wave vector, and $S(\cdot)$ is the directional ocean wave spectrum, and $\delta(\cdot)$ is the Dirac delta function.

The ratio of spectral power density of two Bragg waves has been previously used to estimate the wind direction [2] and is expressed by

$$R = \frac{\sigma_i(\omega_B)}{\sigma_i(-\omega_B)} = \frac{S(-\vec{k}_0)}{S(2\vec{k}_0)}$$

(2)

where the “$\pm$” sign corresponds to the approaching and receding Bragg waves. Typically, the directional ocean wave spectrum has the form

$$S(\vec{K}) = F(K)g(\phi)$$

(3)

where $K$ and $\phi$ are the magnitude and direction of $\vec{K}$ respectively, $F(K)$ represents the non-directional wave spectrum, and the directional spreading function $g(\phi)$ can be described by the Donelan model [8],

$$g(\phi) = 0.5 \beta \text{sech}^2(\beta\phi)$$

(4)

where $\beta$ is the spreading parameter with range[0.1,3] in this paper. $\phi$ is an angle referenced to the mean wave direction. Using the equation (2), (3) and (4), the wind direction $\phi_w$ can be written as

$$\phi_w = \phi_0 \pm \theta$$

(5)

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where $\varphi_0$ is the radar beam direction, $\theta$ is the angle between the wind direction and the radar beam direction given by

$$
\theta = \frac{1}{2\beta} \ln\left| \frac{R^{1/2} e^{i\beta \theta} - 1}{1 - R^{1/2} e^{i\beta \theta}} \right|
$$

To remove this wind direction ambiguity, the “+” or “-” sign in equation (5) should be determined. We have developed ACMB algorithm to eliminate the ambiguity which is applied by comparing the included angles between three adjacent radar beams and the wind direction [6].

In order to retrieve the wind direction, Gurgel proposed a method to find a unique solution by means of least square principle[8]

$$
LSM(\varphi_w) = \left[ R_1 - \frac{g(\pi + \varphi_1 - \varphi_w)}{g(\varphi_1 - \varphi_w)} \right]^2 + \left[ R_2 - \frac{g(\pi + \varphi_2 - \varphi_w)}{g(\varphi_2 - \varphi_w)} \right]^2
$$

where the indices “1” and “2” refer to the two radar sites and $R_1$ and $R_2$ represent the ratio of positive and negative Bragg peaks from the same area which is detected by the tow radar. We apply this algorithm to the wind direction elimination of the monostatic radar and the Eq.(7) can be written as

$$
LSM(\varphi_w) = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[ R_{ij} - \frac{g(\pi + \varphi_i - \varphi_w)}{g(\varphi_i - \varphi_w)} \right]^2
$$

where the index $i$ and $j$ represent the $i$th beam and $j$th range cell. We can choose nine cells to estimate the direction,i.e. $n=m=3$, and $\varphi_i$ represents the $i$th beam direction. Actually the Eq.(8) is one of the calculation way to carry out the multi-beam method by least square principle (LSMB).

3 Data Processing and Analysis with the Algorithms

In this evaluation of the different algorithms for wind direction we are using data from Fujian station over the period 1–31 October 2013. The radar system OS121H has a work frequency of 7.815MHz, which is developed by CSIC Pengli (Nanjing) Atmosphere and Ocean Information System Co. Ltd. The receiving array of the radar system consists of 24 antennas arranged in two rows of 12. The specific parameters of this radar system are listed in Table 1. The in-situ data are proved by an anemometer installed on the buoy, which is deployed in the site about 70km away the HF transmitter station. In the data processing, we use half-hour means of the radar measurements and the same of the in-situ measurements.

<table>
<thead>
<tr>
<th>Technical Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating frequency(MHz)</td>
<td>7.815</td>
</tr>
<tr>
<td>Transmitter power (W)</td>
<td>200</td>
</tr>
<tr>
<td>Radial resolution (km)</td>
<td>5</td>
</tr>
<tr>
<td>Azimuthal resolution (°)</td>
<td>10</td>
</tr>
</tbody>
</table>

The results of the wind direction inverted from the HF radar by ACMB are shown in Fig.1 and the in-situ measurements are also given. From the Fig.1, we can see that most of the wind directions in the in-situ measurements are in the range of 20° to 50°. The majority of the wind directions from radar is bigger than the in-situ measurements. The results of the wind direction inverted from radar by ACMB are shown in Fig. 1 and the in-situ measurements are also given. From the Fig.1, we can see that most of the wind directions in the in-situ measurements are in the range of 20° to 50°. The majority of the wind directions from radar is bigger than the in-situ measurements. The results of the wind direction inverted from radar by ACMB are shown in Fig. 1 and the in-situ measurements are also given. From the Fig.1, we can see that most of the wind directions in the in-situ measurements are in the range of 20° to 50°.
Discussions

In this paper, we use three algorithms to extract the wind direction from an experiment data with a monostatic radar system. The results show that all the three algorithms can all eliminate the ambiguity of the wind direction. And the RMSE obtained by the ACMB algorithm is better than the others, which indicates that the ACMB algorithm is best available for extracting wind direction using the data obtained by this experiment. This accuracy of the results is high in that the wind speed is high and sustained. RMSE of the LSMB algorithm and ML algorithm is closer to the ACMB when data speed above 5.47 m/s used. The RMSE obtained by ML is higher than the others in data processing, however, this does not mean that this algorithm is not fit to extract the wind direction from the single HF radar. The ML method has been
tested in some experiments [3,12]. Further work needs to be done to analyze which algorithm is more available for all kinds of sea state environment by using more experiments data with different conditions.

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References


