Ocean Wind Speed Retrieved from X-Band Radar Image

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Keywords: X-band radar; wind speed; fitting algorithm

Abstract.A method for wind speed retrieval is developed by applying fitting techniques with the ratio of signal to noise. The method is applied to the wind speed retrieval from the nautical radar images. And we get a correlation coefficient of 0.88 and RMS error of 1.34m/s by comparing the data from the radar and in-situ data. The results show that this method can be used to estimate the wind speed.

Introduction

The small-scale roughness of the sea surface is generated by the frictional force of the local wind field[1], which raises the radar backscatter and then the mean radar cross section(RCS) and allows the backscatter to be empirically related to the wind[2].The nautical X-band radar can provide the images of sea surface that include the information of the wind. So the wind speed and direction can be inversed from the nautical radar images. For the inversion of wind speed, Hatten and Seemann studied that the dependence of the spectral noise on the wind speed and developed the linear formula with them[3].Dankert and Horstmann utilized the method of Neural Network (NN) to retrieve the wind speed. However, the accuracy of neural network method depends on the wind direction retrieval[4,5].Also the wind speed can be got by the empirical model related with the significant wave height called SMB. This model can’t be satisfied in all kinds of sea state.

In this paper, a wind speed retrieval method is developed by applying fitting techniques with the ratio of signal to noise reference the method of the significant height retrieval. The method is applied to the wind speed retrieval from the nautical radar images and the results are compared with in-situ measurements, which show a good agreement.

Theoretical derivation

The total variance of the spectral background noise can be used to estimate the accuracy of retrieved ocean wind speed[6]. P. Izquierdo and C. GuedesSoares(2005)[7]developed the linear formula of the spectral noise F_n and the wind speed V, i.e.

$$\sum_{\vec{K},\omega} F_n(\vec{k},\omega) = a + bV \tag{1}$$

where a and b are the fitting coefficients.

For sea state with full development, there is relation between the significant wave height and the wind speed, which is usually called SMB algorithm presented and improved by Sverdrup, Munk and Bretschneideris[8].

$$H_s = \frac{0.26}{g} * V_{10}^2 * \tanh[(f_m V_{10})^{-3/2} \frac{(3.5g)^{3/2}}{10^2} \tag{2}$$

Where g is the gravitational acceleration,$H_s$is the significant wave heights, f_m is the peak period and V_{10} is the wind speed of 10 meters above the sea.

Because the value of function *tanh(x)* is always less than 1, the algorithm requires:

$$V_{10} > 6.143\sqrt{H_s} \qquad (3)$$

The iterative method is used to solve SMB algorithm, which generates successive approximations to the real wind speed by using a given initial value V_{10}.

For nautical radar, the assumption that the square-root of measured signal to noise ratio, SNR, is linearly related to significant wave height, HS,

$$H_s = a + b \times \sqrt{SNR} \qquad (4)$$

where a and b are empirical parameters that have to be determined for each radar. This method has been applied successfully on the inversion of significant height with nautical radar.

According Eq. 2 and Eq. 4, we develop a fitting algorithm to inverse the wind speed,

$$V = a + b \times SNR^c \qquad (5)$$

where a_0， a_1， a_2 are fitting coefficients which have to be determined for each radar.

Data processing and analysis

The data used to test the algorithm were obtained in Fujian of China using the X-band radar wave observation system (OS071X) which is developed by Ocean University of China and CSIC PRIDe (Nanjing) Atmosphere and Ocean Information System Co. Ltd. The system OS071X is composed of one X-band nautical radar, the radar signal processor and a computer installed inversion software to inverse the wave parameter and control the radar. The technical specifications of radar system parameters are listed in Table 1.

Table 1 The specific parameters of the radar system

Technical Specifications	Value
Radar Frequency	9410MHz
Antenna length	2.4m
Radar pulse length	70ns
Pulse repetition frequency	3KHz
Antenna rotation speed	42rpm
Azimuthal resolution	0.1°

In the data processing, we choose 8-day data of the radar measurements with 6minutes interval and the same of anemometer data to test the algorithm. The minimum distance of inversion region is about 1.3km away from the radar site and inversion area is about 1 square kilometers. The inversion region is circled by red line in radar indicator as shown in Fig.1.The results of the wind speed inverted by the fitting algorithm are shown in Fig. 2. We get a correlation coefficient of 0.80 and RMS error of 1.86 m s-1 by comparing the retrieval wind with that from the anemometer. The results calculated by SMB and spectral background noise algorithm are given in Fig.3 and Fig.4 respectively. From the Fig.2-Fig.4, we can see that the results inverted by fitting algorithm match with the in-situ data best among three algorithms.

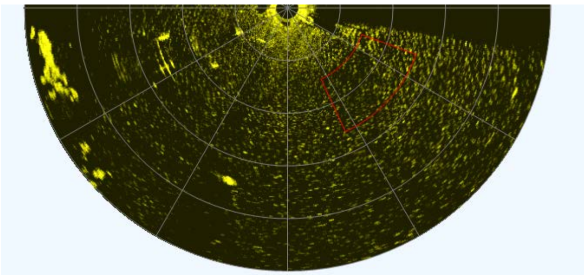

Fig.1.Radar echo images of sea clutter, the red frame to be processed

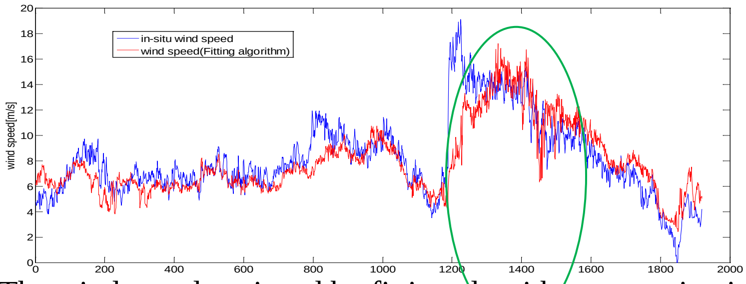

Fig.2.The wind speed retrieved by fitting algorithm versus in-situ data

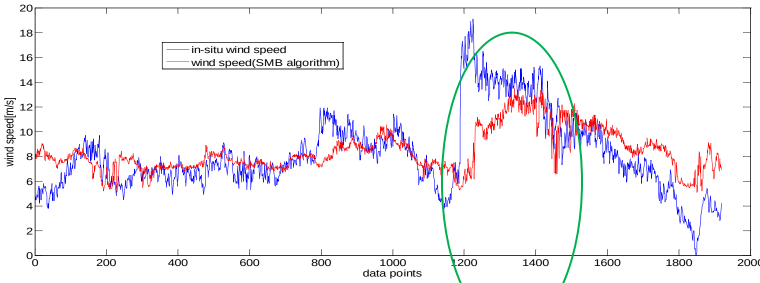

Fig.3.The wind speed retrieved by SMB algorithm versus in-situ data

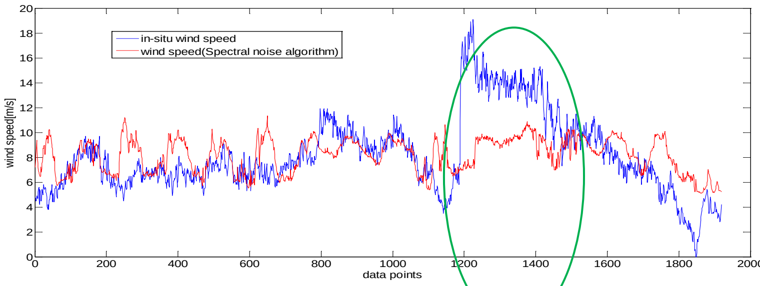

Fig.4.The wind speed retrieved by spectral noise algorithm versus in-situ data

Table 2 Main statistical parameters resulting from three algorithms comparing with in-situ

	Spectral noise algorithm	SMB algorithm	Fitting algorithm
Standard deviation (m/s)	1.93	1.78	1.38
Root mean square error (m/s)	2.81	2.49	1.89
Correlation coefficient	0.440	0.614	0.804

Table 2 shows a full comparison between all three algorithms. Comparing the correlation, root square mean error, and standard deviation among the three algorithms, it is shown clearly that the fitting algorithm is superior to other two algorithms. There are two reasons to affect the results and the noise spectrum is easily contaminated by the background noises, the other reason is that the SMB algorithm is developed for sea state of full development, but in the real ocean there are many different kinds of sea state. Thus, these two methods cannot serve as the generally applicable method. The new method combines the SMB algorithm with the method using in significant wave height retrieval during the retrieval process, which can improve the accuracy and enhance the applicability.

In Fig.3 andFig.4, the results in the range 1200-1300 sample points have a large discrepancy. The in situ wind speed changes from about 6m/s to 16m/s, which varies so rapidly that it is not effect on the wave. In other words, the wave can't reflect on the change of the wind speed. The inversion of wind speed depends on the nautical radar monitoring the sea surface wave. So there is a big difference between the inversion results from the radar and the in situ data.

We find that there are influences of rain drops and ships on the data. The Fig.5 gives the radar image including noises of the rain and the ship. We get rid of about 76 sample data including the noises from the rain drops and ships and the remainder data are calculated again. The correlation, root square mean error, and standard deviation between the in situ and radar are given in table 3.

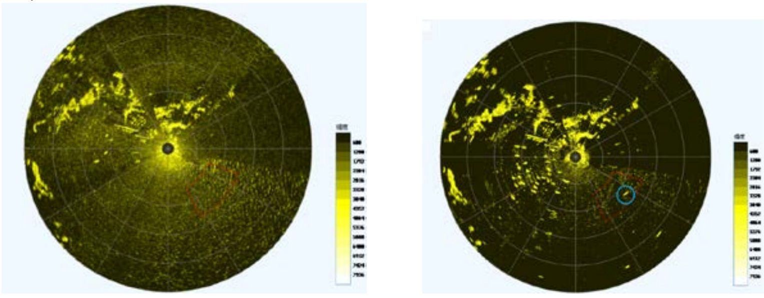

Fig.5.Sampleimages of rain drops' and ships' effects(left: effect of rain drops; right: effect of ships, the circle)

Table 3 Main statistical parameters resulting comparison of wind speed between in-situ and SMB, Fitting algorithm before or after noise eliminating

	SMB algorithm		Fitting algorithm	
	Before noise eliminating	After noise eliminating	Before noise eliminating	After noise eliminating
Standard deviation (m/s)	1.78	1.19	1.38	0.79
Root mean square error (m/s)	2.49	1.91	1.89	1.34
Correlation coefficient	0.614	0.778	0.804	0.882

The Table 3 shows that the RMS error of wind speeds retrieved by fitting algorithm is reduced from 1.89m/s to 1.34m/s and the correlation coefficient is increased from 0.804 to 0.882 after we eliminate the influence of the rain and ship. From the fig. 6, the wind speeds retrieved from the fitting algorithm is well distributed around the line y=x, so the fitting algorithm is more stable than SMB algorithm. When the in-situ wind speed is<5m/s, the retrieved values from the fitting algorithm and SMB algorithm are higher than the in-situ wind speed, which is caused by the larger interference of the background noise under the low wind speeds.

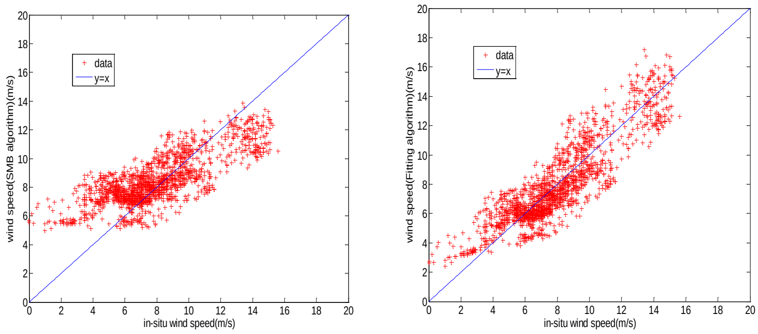

Fig.6.Comparison of in-situ and retrieved wind speeds after the quality control (left:SMB algorithm, right:fitting algorithm)

Discussions and Conclusions

This paper provide a new algorithm to extract wind speed from the image sequences of X band nautical radar. This algorithm can be implemented by establishing the relation between the wind speed and the signal noise ratio. We get a correlation coefficient of 0.88 and RMS error of 1.34m/s by comparing the data from the radar and in-situ data over an 8-day period. The spectral noise algorithm and SMB algorithm are also applied and the results are analyzed. The results show that the results calculated by fitting algorithm and in-situ data are in best agreement and the algorithm can be utilized to estimate the wind speed.

Acknowledgments

This work was supported by National Natural Science Foundation of China (Grant No. 41206164).

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