An Improved Method on the Wave Height of Ocean Surface Based on X-Band Radars

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Abstract. It contains plenty of ocean wave and sea surface current information in the sea clutter images formed by X-band marine radar's echo. Applying the method to calculate the significant wave height from the SAR imagery, which supposes the significant wave height in linear relation with the square of the signal-to-noise ratio of radar images, the significant wave height has been obtained from estimating the images of X-band radar. The experimental data were analyzed in the Small Mai-island sea area. Firstly comparing the effect of filtering direct current versus estimating result, deriving the significant wave height estimated by counting the signal-to-noise ratio after filtering direct current which is match better; then according to wave height measured by wave buoy, analyzing low and high wave height to do linear fit and gain calibration coefficient separately, the significant wave height evaluated is all the more precise.

Keywords: X-band radar · Significant wave height · Filtering direct current Linear fit

1 Introduction

Waves is a with the human relations is the most direct and most closely ocean phenomenon, the wave height, wave direction on defense, shipping, ports, and the safety of offshore oil platform has very important significance. Marine navigation of x-band radar echo of the sea clutter image contains abundant waves, sea surface layer information. Using x-band radar imaging mechanism, by studying the relationship between image spectrum and wave spectrum, can make use of the radar echo intensity inversion of wave spectrum and sea state parameters.

However, compared with the in-situ observation instruments such as the wave buoy, in the direction of the waves from radar image spectrum inversion, can only get the direction of wave spectrum energy relative not get its absolute value. In 1982, Alpers and Hasselmann [1] proposed from synthetic aperture radar (SAR) image to obtain the effective method of wave height, the basic idea of this method is to assume

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that the significant wave height and from the square root of the signal-to-noise ratio of radar image into a linear relationship, calculated by the signal-to-noise ratio of radar image, significant wave height. In 1994, Ziemer and Gunther [2] for the first time the application of the method of significant wave height is obtained from SAR on the radar, and by using this method by navigation radar image got significant wave height. In 1998, Nieto et al. [3] and others also use this method by the navigation radar image obtained the significant wave height. Especially the method has been successfully used in deep water.

We developed on the basis of x-band radar 'sea Wave flow Information extraction System (Wave and Current Information Extracting System)' abbreviated as 'WCIES', mainly including the x-band radar, signal acquisition and preprocessing System and the surface Wave flow Information extraction software of three parts. We mainly wheat island shore-based experiment was carried out in Qingdao, WCIES will get significant wave height and significant wave height were compared from the wave buoy. The first part of the article mainly introduces the radar image theory of inversion algorithm steps; The second part gives the calculation method of effective wave height; The third part will be the improved method is applied to the experiment data processing, from two cases respectively for wheat island analysis of experimental data in detail; The fourth part gives the experiment results analysis and summary of this article.

2 The Inversion Algorithm of Radar Image

FAs the waves and currents from radar image time series information, select a rectangular area on radar image, corresponding area of the sea. Radar antenna per rotation week, form a picture of a radar image, the area 64 consecutive radar image, modulus conversion of analog signals, will receive the digital signal is stored as a radar image of time series, then the following processing [4].

(1) Image coordinate transformation: due to radar image extracted by polar coordinates are the coordinates of the corresponding time series, and Fourier transform, the radar image corresponding to the polar coordinates conversion become rectangular coordinates, extraction of pending rectangle radar image grey value with the distribution of space time $g(x, y, t)$.
(2) Discrete Fourier transform, using the discrete Fourier transform [4] will be 64 consecutive radar image into a 3d image spectrum, $I^{(3)}(k_x, k_y, \omega)$.
(3) The determination of surface flow: to compare the image spectrum energy location and determined based on the dispersion relation of spectral energy position, with the least square method to determine the surface flow [5].
(4) Three-dimensional image spectrum filter: use gravity waves meet the dispersion relation of the image spectrum band pass filter, wave energy separated from background noise [4].
(5) Determination of two-dimensional wave spectrum: the 3d image spectrum in frequency range is integral, obtaining two-dimensional image spectrum $I^{(2)}(k_x, k_y)$, then reusing the modulation transfer function [2, 6], and getting the wave spectrum $F^{(2)}(k_x, k_y)$.

(6) The calculation of wave direction spectrum: The two-dimensional wave spectrum from wave number space transformation to the frequency domain space, get the direction of wave spectrum.

3 Significant Wave Height Inversion

M Due to the nonlinear wave imaging mechanism [4], the waves of significant wave height can not directly from radar image. In 1994, Ziemer and Gunther [2] for the first time Alpers and Hasselmann [1] and others get significant wave height from SAR image method is applied to Marine radar. This method assumes that the significant wave height and the square root of the signal-to-noise ratio of the radar image into a linear relationship, namely

$$H_s = A + B\sqrt{SNR} \tag{1}$$

where A, B are undetermined constants, determined by the radar system, the Hs is the significant wave height of ocean waves, SNR is the signal-to-noise ratio of the radar image. Signal-to-noise ratio SNR is defined as

$$SNR = \frac{SIG}{BGN}, \tag{2}$$

where SIG is the energy of the wave spectrum.

$$SIG = \sum_{i=1}^{N} F^{(2)}(k_{xi}, k_{yi})\Delta k_x \Delta k_y, \tag{3}$$

where BGN is the energy of the background noise.

$$BGN = \sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\sum_{l=1}^{N_t} I^{(3)}(k_{xi}, k_{yj}, \omega_l)\Delta k_x \Delta k_y \Delta\omega - \sum_{i=1}^{N} I^{(2)}(k_{xm}, k_{ym})\Delta k_x \Delta k_y \tag{4}$$

where $F^{(2)}(k_x, k_y)$ is the inversion of wave spectrum, $I^{(3)}(k_x, k_y, \omega)$ is three-dimensional images after the three dimensional Fourier transform spectrum, $I^{(2)}(k_x, k_y)$ is the two-dimensional image spectrum. N is the coordinates of image spectrum meeting the dispersion relation, N_x, N_y, N_t are coordinates of wave number after Fourier transform, the frequency component respectively. $\Delta k_x, \Delta k_y$ are wavenumber resolution, and $\Delta\omega$ is angular frequency resolution.

4 The Experiment and Data Processing

Wheat Island is located in the southeast of Qingdao, in north latitude 36º03′ , east longitude 120º25′, its waters vision, convenient for observation, is an exploration into the island sea area of about 1 km^2. In February 2007 on March 17, 7 solstice radar YingHai villa roof frame with wheat island platform shore-based tests have been carried out. Radar antenna about 20 m, from sea level in waters of radar detection, with the state oceanic administration of wheat island hydrometric station cloth wave buoy, obtained by radar image can be achieved with the waves than the measurement information. During the experiment period, navigation radar and signal acquisition system was operating, on the sea, and the observed data were recording and storing. Test of the project group's people on duty. General requirements of timing acquisition data, the data acquisition time depending on the sea state, if the sea state is higher, the waves is bigger, will increase the sampling density, such as collect data once every 10 min.

In data processing, we choose several groups of radar image data, (2)–(4) is used to calculate SNR, then On the SNR data and effective wave height wave buoy measured data, using the least squares linear fitting to determine the parameters of A and B.

4.1 The Dc Filter

On radar image gray value varies with space time distribution of the three dimensional Fourier transform, that is, before considering the dc signal component influence on the result, the direct Fourier transform and Fourier transform of the reentry after dc filter, which divided into dc filter and NO dc filter. Dc filter calculation method is as follows.

$$g(x, y, t) = g(x, y, t) - \bar{g}(x, y, t) \tag{5}$$

Where $\bar{g}(x, y, t)$ is for the average of $g(x, y, t)$. Calculate SNR before, not for dc filter, namely the direct Fourier transform. Chosen wheat island shore-based experimental part of the data of linear fitting results are shown in Fig. 1.

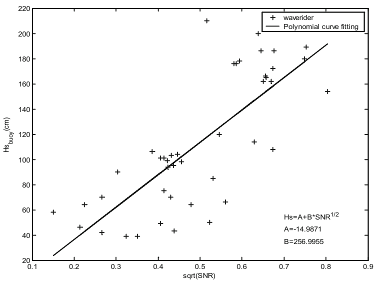

Fig. 1. Least-square fit to obtain the calibration parameters, A and B

From Fig. 1 the relation could be obtained A = –14.9871, B = 256.9955. Therefore, for the selected radar system (Fig. 2),

$$H_s = -14.9871 + 256.9955\sqrt{SNR}\,(\mathrm{cm}) \tag{6}$$

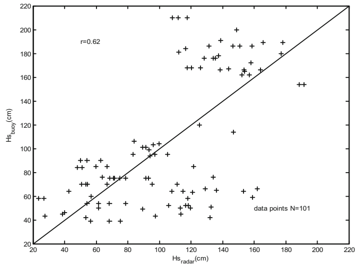

Fig. 2. Scatter plot of the significant wave height (Hs) obtained by the radar and buoy. The correlation coefficient is r = 0.62.

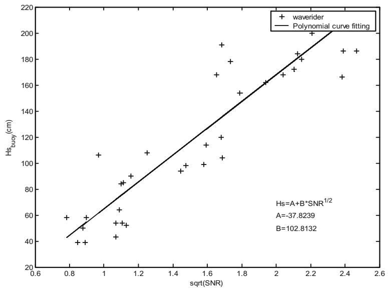

Fig. 3. Least-square fit to obtain the calibration parameters, A and B

Before calculating the SNR, first of all, dc filtering of Fourier transforms. Part of the data of wheat island shore-based experimental were chosen for linear fitting, the results as shown in Fig. 3.

From Fig. 3 the relation could be obtained A = –37.8239, B = 102.8132. Therefore, for the selected radar system (Fig. 4),

$$H_s = -37.8239 + 102.8132\sqrt{SNR}\,(\mathrm{cm}) \tag{7}$$

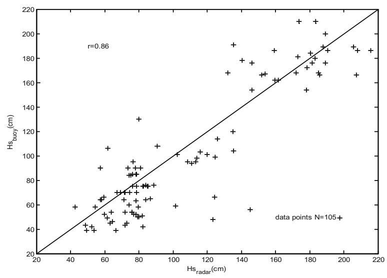

Fig. 4. Scatter plot of the significant wave height (Hs) obtained by the radar and buoy. The correlation coefficient is r = 0.86.

4.2 Takanami High and Low Wave

To make more accurate measurement results, according to the wave buoy is the significant wave height of size, it can be divided into two segments, wave height and wave height lower part of the higher the takanami high and low wave height to processing respectively. By (1), the signal-to-noise ratio of the size of the corresponding to the size of the significant wave height, the experimental results show that the size can be according to the calculated signal-to-noise ratio to block, experiments in SNR = 2.8269 is bounded. The following to calculate SNR before $g(x, y, t)$ dc filter after the data analysis. The high takanami part linear fitting the data was shown in Fig. 5. From Fig. 5 the relation could be obtained A = 109.9281, B = 32.5748. Therefore, for the selected radar system,

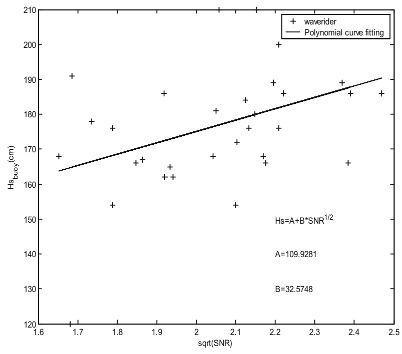

Fig. 5. Least-square fit to obtain the calibration parameters, A and B

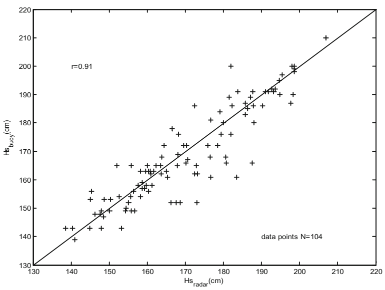

Fig. 6. Scatter plot of the significant wave height (Hs) obtained by the radar and buoy. The correlation coefficient is r = 0.91.

$$H_s = 109.9281 + 32.5748\sqrt{SNR}\,(\mathrm{cm}) \tag{8}$$

The low wave high part of the linear fitting the data was shown in Fig. 7. From Fig. 7 the relation could be obtained A = –9.0127, B = 69.3173. Therefore, for the selected radar system (Figs. 6 and 8),

$$H_s = -9.0127 + 69.3173\sqrt{SNR}\,(\mathrm{cm}) \tag{9}$$

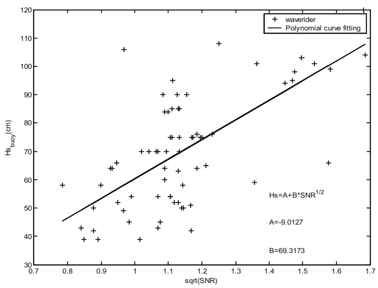

Fig. 7. Least-square fit to obtain the calibration parameters, A and B

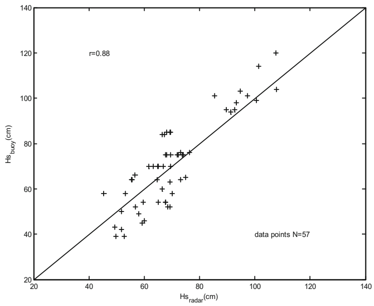

Fig. 8. Scatter plot of the significant wave height (Hs) obtained by the radar and buoy. The correlation coefficient is r = 0.88.

5 Conclusion

Use we developed on the basis of x-band radar waves flow information extraction system, through the analysis of the radar echo intensity, can get sea state parameters of Marine dynamic environment, but the surface of the significant wave height can directly by the radar image sequences to get time. Using Alpers and Hasselmann [1] and others get effective method of wave height from SAR image, can get the waves from the radar image of significant wave height.

From the analysis of experimental data, the dc data after filtering, linear fitting by least square, and which are obtained by inversion, the wave buoy measured significant wave height in accordance with good, and the correlation coefficient is higher; According to the wave buoy wave height will be divided into high reflection of high and low wave to deal with, from the point of the results, their correlation coefficients are higher than when you don't separate, and conform to the better. In practice, can according to the size of the SNR of separate high and low wave height, in this experiment we take SNR is equal to 2.8269. According to the result of calculation shows that the radar image grey value of dc filter and wave height can be divided into two wave height can be considered as a better processing method to analysis, fitting coefficient can be used in practical radar system. Need to point out that our rich data quantity is not enough, if there is enough data, the result will be better.

References

1. Alpers, W., Hasselmann, K.: Spectral signal to clutter and thermal noise properties of ocean wave imaging synthetic aperture radars. Int. J. Remote Sens. **3**, 423–446 (1982)
2. Ziemer, F., Gunther, H.: A system to monitor ocean wave fields. In: Proceedings of the Second International Conference on Air-Sea Interaction and Meteorology and Oceanography of the Coastal Zone, Lisbon, Portugal (1994)
3. Nieto, J.C., Reichert, K., Dittmer, J., et al.: WaMoS II: a wave and current monitoring system. In: Proceedings of the COST 714 Conference on Directional Wave Spectra, Paris (1998)

4. Nieto, J.C., Hessner, K., Reichert, K.: Estimation of the significant wave height with X-band nautical radars. In: Proceedings of OMAE 1999 St. John's, Newfoundland, pp. 11–16, July 1999
5. Senet, C., Seemann, J., Ziemer, J.: The near-surface current velocity determined from images sequences of the sea surface. IEEE Trans. Geosci. Remote Sens. **39**, 492–505 (2001)
6. Ziemer, F., Rosenthal, F.W.: On the transfer function of a shipborne radar for imaging ocean waves. In: Proceedings of IGARSS 1987 Symposium, Ann Arbor, Michigan, May 1987