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Influence of Rainfall Elements to Wave Analysis from X-band Radar Images

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ABSTRACT

Ocean waves features are random and dependent on meteorological, hydrological, oceanographic and topographical factors. Remote sensing techniques have become quite popular for ocean wave measurement applications. The X-band radar which has capability to capture the temporal and spatial wave information, is the potential instrument for wave measurement. This paper aims to study the influence of rainfall elements to wave analysis from marine radar images. In order to differentiate between the radar images with rain noise and without rain noise. Mean value and variation coefficient of radar signals are proposed in this study. It is found that the degree of accuracy of Radar images is higher than 95%. It is also proposed frequency domain filtering to filter the rain noise which occur in radar images. It is found that there are about 16% radar images with rain noise can be filtered successfully.

1. Introduction

Ocean wave information is required for various purposes, such as coastal engineering, environment protection, port operations, disaster prevention, rescue and so on. Theoretic analysis, laboratory experiment, numerical simulation and field measurement are common methods to obtain wave data. Because the features of ocean waves are extremely random, and the characters of ocean waves are effected by meteorological, hydrological, oceanographic and topographical factors directly or indirectly, they often can not be fully understood only by theoretical or numerical approaches. Field measurement must be performed to increase the knowledge of waves. Diverse ways of wave measurement have been investigated since last few decades. They may be categorized as in-situ measurement and remote sensing technique. At present, various methods of in-situ measurement have significantly developed and improved to better quality. However in-situ measurement is not easy to collect wave information of spatial domain. The remote sensing technique has good capability to observe large spatial ocean wave information. Remote sensing images present the spatial pattern by microwave echoes after a series of electromagnetic pulses is transmitted towards the ocean. The variation of water surface presented in the images is the intensity of backscatter. Remote sensing images record the distribution of back scattering strength of sea surface. The wave parameters can be estimated from spectrum which can be analyzed from sea clutter images.

Wave remoteing sensing technology can be divided into optics and Radar observation. Due to the permeability of electromagnetic waves, Radar observation can be operated day and night, carries on all-weather observation in theory. The present wave observing technologies by Radar are included Synthetic Aperture Radar (SAR), high-frequency radar, X-band radar and so on. Because of the operations research and economy purpose, this study choose X-band as the tool in wave observations and researchs.

According to the basic principles of X-band Radar, the capability of observation would be influenced by the deacy dergee in the course of atmosphere. It is mainly influenced by the handicap and aqueous vapor coagulum (include rain drops, fog, mist, cloud, snow etc.). The navigation radar of X-band which is used in this study is one kind of microwave radar. In theory, the microwave radar is free of climatic conditions basically in measurement, that is to say that the microwave radar has function of piercing through cloud, smog and rain, But not all bands of microwave can be unfluenced on climatic factors. If the wavelength of the microwave is smaller than 4 cm, the influence of the rain can't be neglected. Due to the wavelength of X-band Radar is 3.2cm, the influences which are caused by rain are obvious.

Hence, the purpose of this study is to consider the influence of rainfall factors in X-band Radar observation, for the purpose of getting more accurate sea state information from Radar images. It is proposed a method to identify Radar images are effected by rain noise or not. In addition, it is also proposed a method for filtering rain noise on Radar images in our study.

2. The Influence on Radar Scatter by Rainfall Noise

2.1 Basic Principle of Radar Observation

The basic observating theorem of Radar observation is to produce the electromagnetic wave of a certain specific frequency from the transmitter of Radar, the electromagnetic wave energy towards the ocean surface via aerial. If the electromagnetic wave meet ocean wave surface, some electromagnetic wave would be returned, and sea clutter is received by the receiver of Radar antenna. According to digitize sea clutter signal and analyze it, ocean information can be obtained. The mechanisms of radar scattering from ocean wave surface can be divided into specular reflection and Bragg scattering (Doong, 2002).

The strength of specular reflection is mainly determined by the slope or the gradient of ocean wave surface. If the surface of ocean wave is almost vertical, that is to say the direction of radar wave is nearly orthogonal to the ocean wave surface, and the reflecting amount of electromagnetic wave is stronger than other angle between radar wave direction and ocean surface. Generally speaking, if ocean wave height is higher, the reflecting area from wave surface is stronger, and the reflecting amount of electromagnetic wave is more than peaceful sea state.

Bragg scattering is another main mechanism of electromagnetic wave back scattering, it is described the interation between electromagnetic waves and ocean waves in this theory. If the relationship between the wavelength of electromagnetic wave and ocean wave correspond wth Eq.(1), the sea clutter would be strengthened, where λ_w is the wavelength of ocean wave, λ_r is the wavelength of electromagnetic wave and θ is the grazing angle of electromagnetic wave.

$$\lambda_w = \lambda_r / (2\cos\theta) \tag{1}$$

For the sake of the wavelength of X-band radar wave is 3.2cm, it will produce Bragg scattering for the capillary wave with the wavelength of 1.85cm if the grazing angle is 30 degrees.

The relevant wave parameters which are obtained by X-band Radar are calucated by sea clutter indirectly. If sea clutter information is influenced by external factors, the characters of sea clutter signal may be effected, even may be unable to be analysed, or obtain wrong answers.

2.2 The Influences on Radar Sea Clutter from Rainfall

With reference to the researchs of radar sea clutter which is influenced from rainfall, Moore et al. (1979) studied on the scatterometer observation. It was proved that radar backscatter will be influenced by rainfall, and it was also found that the size of raindrop is the key factors. Moore et al. (1997) calculated the rainfall by using SIR-C/X-SAR satellite observating data. It is considered that rainfall would strengthen the intensity of rain noise on the Ramote sensing images, so it could be calculated the rainfall by the intensity of radar backscatter.

For X-band radar with 9.4GHz frequency, it only make extremely slight decay of radar electromagnetic wave by the gas in atmosphere. So in this study, we focus on the research of radar wave influence by rainfall. With the increase of raining intensity and the size of rain drops, the influence of rainfall would be become the main factor of the Radar sea clutter. Generally speaking, the influence of sea state observating by Radar in raining condition, it can be summed up the following phenomena (Yang, 2004). First, rainfall will change the noise intensity of Radar images, and it may not be identified the wave patterns in heavy raining condition. Second, the existence of the rain drops would decay and scatter the electromagnetic wave in atmosphere, and it will reduce the range of Radar observation. Third, after the rain drops on water surface, water surface would become rougher. The roughness of sea surface would effect the intensity of sea clutter, it would also effect the accuracy of sea state analysis from Radar images. Fourth, due to rain drops strike water surface, it would cause the perturbation under water, the perturbation would strengthen the viscosity of water body, and smooth water surface. Because these four phenomena occur synchronously, it would make radar sea clutter more complicate.

2.3 The Characters of Radar Sea Clutter Images with Rain Noise

The impact on Radar sea clutter with raining is the form of miscellaneous spots which appears in Radar images, the characters of these miscellaneous spots would be influenced on the rainfall and the size of rain drop. Under the situation of heavy rainfall, rain noise would become the main element in Radar images, please refer to Fig. 1 and Fig. 2. The analyzed result of the Radar images is shown as Fig. 3, it shows the relationship between significiant wave height data which are maesured from Radar and Data Buoy. It is found that the difference between Data Buoy wave height and Radar wave height can not be ignored if Radar images are effected with rain noise. Due to the obvious differences of wave height analysis result between in-situ observation and Radar observation with raining, it should be understood that Radar images are influenced by rain noise or not. Hence, this study research the methods to identify Radar images are effected by rain noise or not, and try to filter rain noise from Radar images.

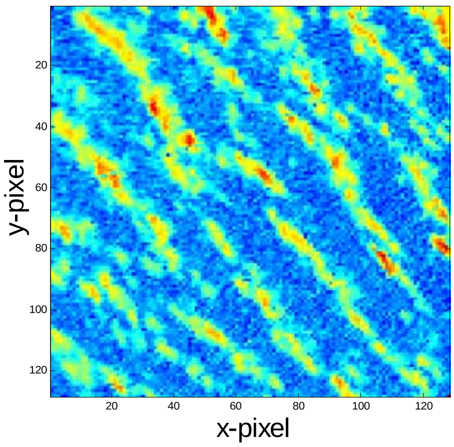

Fig1. Radar Image without rain noise

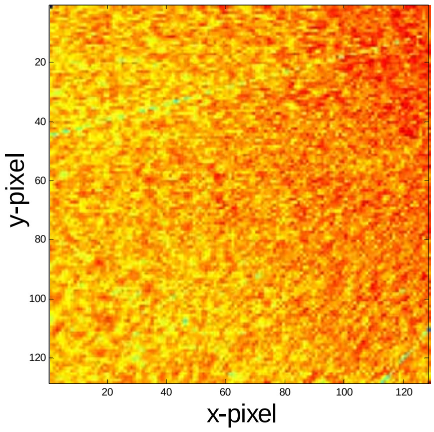

Fig2. Radar Image with heavy rain noise

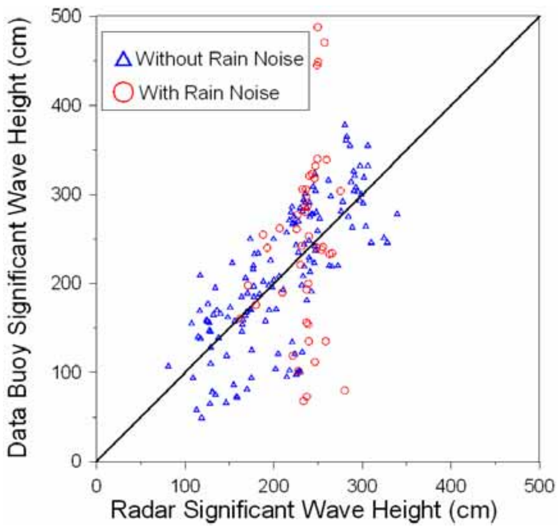

Fig3. The relationship between Radar and Data Buoy significiant wave height

3. Classification and Filteration of Radar Images with Rain Noise

3.1 Classification of Radar Images

Generally speaking, there are two kinds of obvious statistics characters which are sensitive with rain noise on Radar images. Because rain drops would strengthen the intensity of rain noise, the average intensity of sea clutter with raining is higher than that without raining. In addition, the influence of rain noise is similar to a block which covers on Radar image, so the variation of Radar image with raining is smaller than that without raining. Hence, it is applyed the mean value and the variation codfficient of Radar image to determine Radar images are influenced by rain noise or not. The equation of variation coefficient (CV) is shown as Eq.(2), where σ_x is the standard deviation of each Radar image and μ_x is the mean value of each Radar image.

$$CV = \frac{\sigma_x}{\mu_x} \tag{2}$$

The relationships between the mean value, variation coefficient and signal to noise value of Radar images are shown in Fig. 4 and Fig. 5. It is found that the mean value and the variation codfficient of Radar images are indeed different with raining or without raining. Hence, it can be classified by determining the threshold of the mean value and variation codfficient of Radar images. In this study, we classify Radar images by the mothod of above-mentioned, it is found that the successful rate of classifying Radar images is over 95%.

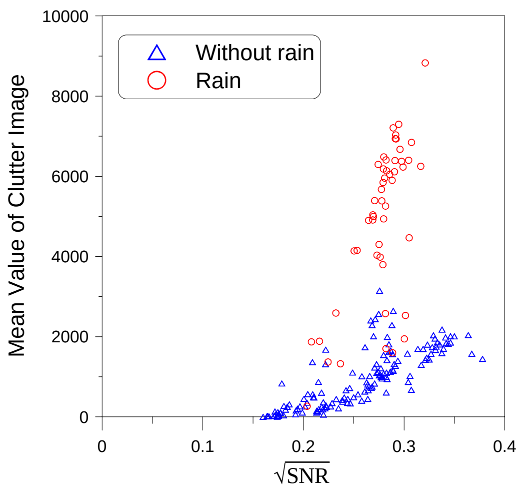

Fig.4 The relationship between the mean value and the square of signal to noise value

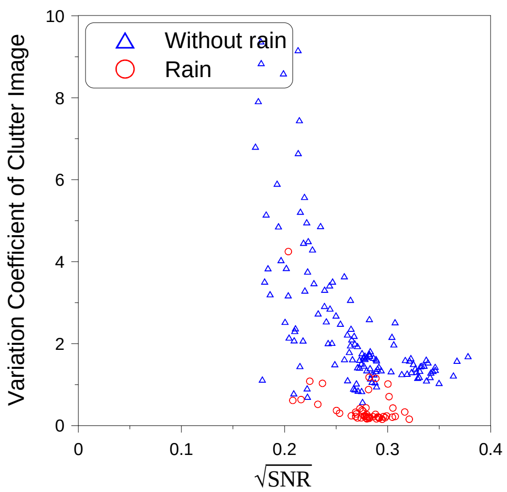

Fig.5 The relationship between the variation codfficient and the square of signal to noise value

3.2 Application of Filteration in Reducing Rain Noise on Radar images

After identifying rain noise from Radar images by mean value and variation coefficient, this study try to separate rain noise from sea clutter on Radar images. Due to the difference between rain noise and sea clutter in the spatial frequency domain of Radar images, this study apply frequency domain filtering to reduce the influences of Rain noise on Radra images. The flow of analysis is shown as Fig. 6. At first, Radar images need to be transformed to the spatial frequency domain by Fourier Transform. It is applyed bandpass filter to reduce rain noise from Radar images. For the sake of filtering rain noise correctly, it's necessary to determine an applicable cut-off frequency of filter function. The method to determine the cut-off frequency of filter function is discussed as follows. In order to character a approximate ocean wave form, it needs 5 sample points at least if the ocean wave form is suppose as sine or cosine wave form (Please refer Fig.7). Because the spatial resolution of Radar image which are used in this study is 7.5 meter per sampling point. That is to say, the length of ocean wave should be longer than 37.5 (=5×7.5) meter at least if we want to analyse the characters of ocean wave from Radar images with the resolution is 7.5 meter per sampling point. Hence, the upper cut-off frequency is seted as 0.17rad/m ($=2\pi/37.5$).On the other side, due to the possibility of the ocean wave over 20 seconds period is very seldom, and it can be calculated the wave length is about 624 meter by wave dispersion relation theory. the lower cut-off frequency is seted as 0.01 rad/m ($=2\pi/624$). The filtering function is shown as Fig. 8, and this study make the gradual progress in the transitional area of cut-off frequency.

The result of Radar images analysis shows that it can be improved the accuracy after filtering the rain noise from Radar images (Please refer to Fig. 9), but only about 16% Radar images with rain noise can be filtered successfully, and Radar images which can not be filtered successfully are parts of the observated cases with heavy rain.

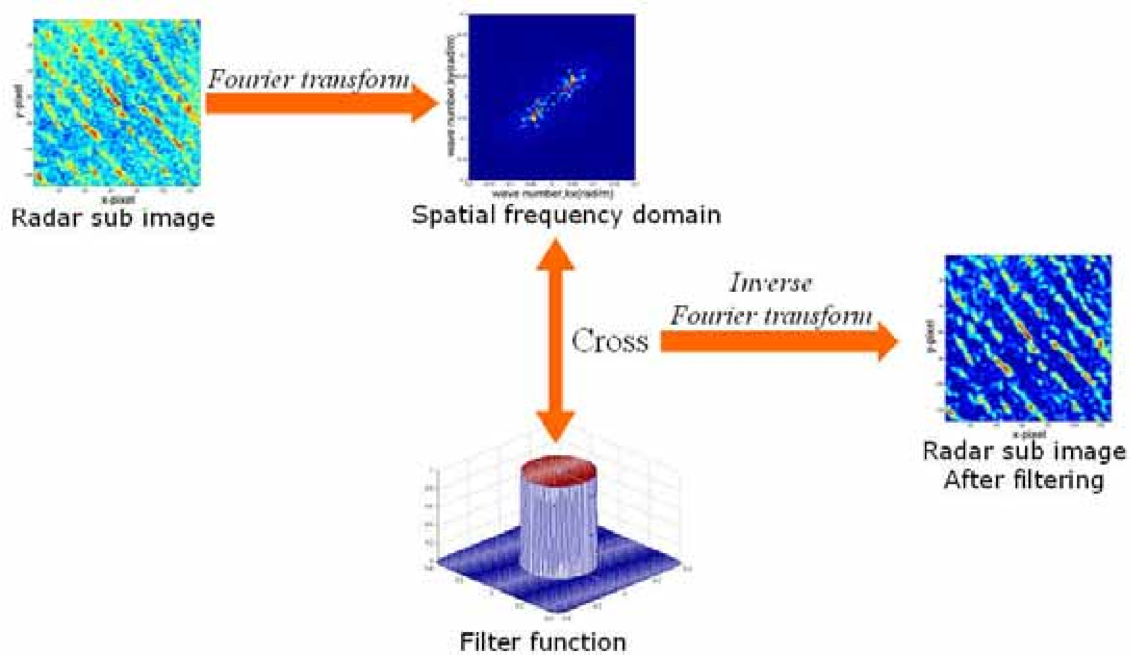

Fig.6 The flow of rain noise filtering from Radar image

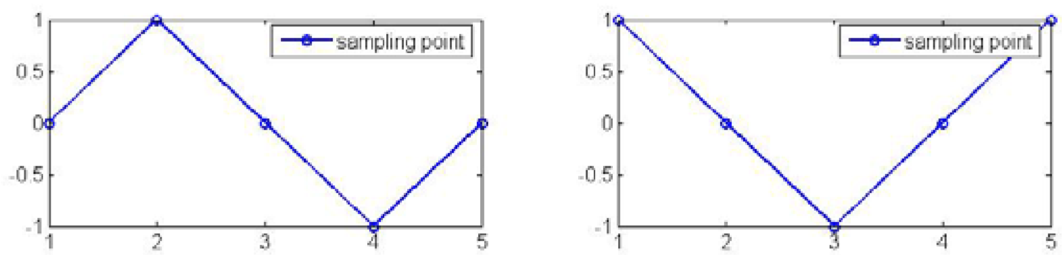

Fig.7 The diagram of charactering an approximate sine and cosine wave form

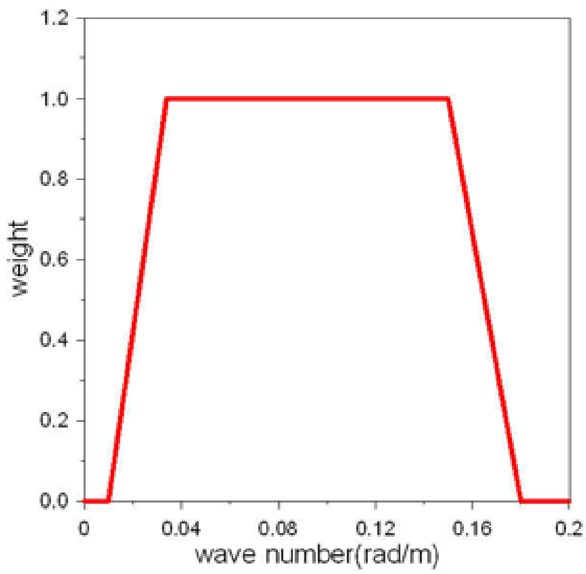

Fig.8 The filtering function which are designed in this study

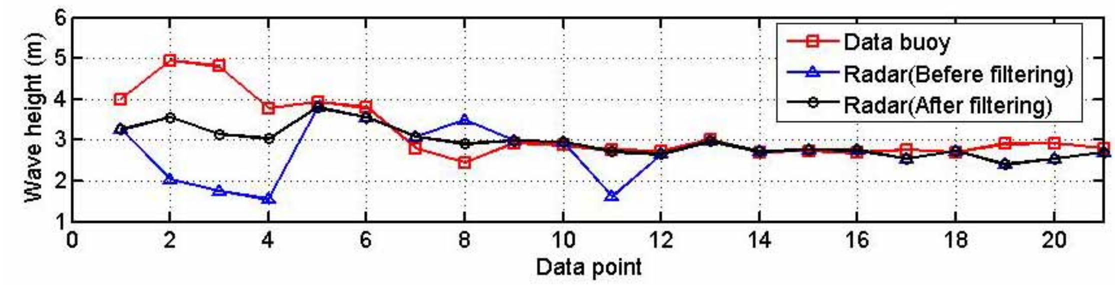

Fig.9 The relationship between the wave height measured from Data Buoy and Radar

4. Summary

In this study, we aims to study the influence of rainfall elements to sea states analysis from X-band Radar images, and improve the accuracy of Radar observation in raining case. In order to differentiate sunny or raining cases from Radar images, this study propose applying the mean value and variation codfficient of Radar images to classify Radar images. It is found that the successful rate of identifying Radar images is over 95%.

This study also design a filter function to separate rain noise from sea clutter on Radar images. It is determined the cut-off frequency by considering the characters of wave.. The result of Radar images analysis shows that it can be improved the accuracy of wave height calucation after filtering the rain noise from Radar images, but only about 16%

Radar image cases with rain noise can be filtered successfully, and Radar images which can not be filtered successfully are parts of the observated cases with heavy rain.

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References

1.Crombie, D. D. (1995) "Doppler spectrum of sea echo at-13.56 MHz," *Nature*, 4459, pp. 681-682.

2.Doong, D.J. (2002) "Uncertainty assessment of wave remote sensing", PhD thesis, National Cheng Kung University, Tainan, Republic of China.

3.Long, M. W. (1974) "On a two-scattered theory of sea echo," *IEEE Transactions on Antennas and Propagation*, AP-22, pp. 667-672.

4.Moore, R. K., Y. S. Yu, A. K. Fung, D. Kaneko, G. J. Dome, and R. E. Werp (1979) "Preliminary study of rain effects on radar scattering from water surfaces," *IEEE Journal of Oceanic Engineering*, Vol. OE-4, No. 1, pp. 31-32.

5.Moore, R. K., A. Mogili, Y. Fang, B. Beh, and A. Ahamad (1997) "Rain measurement with SIR-C /X-SAR," *Remote Sensing of Environment*, Vol. 59, No. 2, pp. 280-293.

6.Yang, Y.T. (2004) "Influence of Meteorological Elements to the Ocean Wave Analysis from Marine Radar Images", MD thesis, National Cheng Kung University, Tainan, Republic of China.