THE EXTRACTION OF 2-D SEA PARAMETER AT NEAR SHORE REGION FROM SEQUENCE ANALYSIS OF MARINE RADAR IMAGE AND ITS VERIFICATION

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ABSTRACT

The Observation of 2-D wave parameter distribution is important for estimating the wave force to marine constructions, such as jetty. The in situ data routinely observed now are point data and the cost is expensive, so the number of observation point is a few. There is no routine method for monitoring 2-D wave parameter distribution.Marine radar can offer the image of 2-D wave field by monitoring the sea clutter from the sea surface.
In this study we observed the wave parameter around the coast area near Komatsu city besides Sea of Japan by marine radar from Jan.8 to Jan.11, 1996 when the highest significant wave in winter of 1996's was observed. From Image of marine radar we obtained the wave direction and wave speed by optical flow estimation. Wave direction and wave speed were calibrated by the result of FFT and in situ data by Ministry of Construction Japan. The Accuracy of wave direction fits to the in situ data. But the accuracy of wave frequency is lower than wave direction. To examine this correlation, the nonlinearity caused by wave breaking was investigated with the simulation study using in situ measurements.

1. INTRODUCTION

The Observation of 2-D wave parameter distribution is important for the estimation of the wave force to marine constructions, such as jetty. The in situ data routinely observed now are point data and the cost is expensive, so the number of observation point is a few. There is no routine method for monitoring 2-D wave parameter distribution.
Marine radar can offer the image of 2-D wave field by monitoring the sea clutter from the sea surface. F.Ziemer,and W.Rosenthal[1)] was developed the transfer function for marine radar for imaging ocean waves. After applying the transfer function to the image spectra, significant wave heights were estimated and compared with results from other sensors during LEWEX[2)]. Results of their study are very promising. And M.D.Henschel et al[3)] developed the prototype marine radar ocean wave imaging system, MACRADAR, for validation of the ERS-1 SAR wave mode operation by using F. Ziemer et al 's method. But their application was carried out only on the offshore region.
In this study we observed the wave parameter around the coast area near Komatsu city besides Sea of Japan by marine radar from Jan.8 to Jan.11, 1996 when the highest significant wave in winter of 1996's was observed. From Image of marine radar we obtained the wave direction and wave speed by optical flow estimation. Wave direction and wave speed were calibrated by the result of FFT and in situ data by Ministry of Construction Japan.
The Accuracy of wave direction fits to the in situ data. But the accuracy of wave frequency is lower than wave direction.

2. METHODOLOGY OF WAVE PARAMETER DETECTION

2.1 Wavelength and Wave Direction by FFT

Fig.1 shows the flow diagram of analysis procedure. As the received power from the sea surface become more and more weakly as the radar is far from the radar site. The correction function are applied to correct the difference of these power due to the distance from the radar to the sea surface. And the received power from the radar is PPI image shown as Fig.2 on polar coordinate system, so the image is transformed to x-y coordinate system for FFT analysis.The Fourier transformation $F(kx,ky)$ is defined by

$$F(kx,ky)=1/(2\pi)^2 \cdot \iint_{\infty}^{\infty} \eta(x,y) \cdot \exp(-i(kxx+kyy))dxdy \quad \text{.....................} \ 1)$$

$\eta(x,y)$ is the radar image defined on x-y coordinate system. And Wave number spectrum is defined by

$$S(kx,ky)= | F(kx,ky)^2 | \quad \text{.......................................} 2)$$

The relationship between wave number spectrum and 2-D wave parameter is shown in Fig.3.
We use the discrete Fourier component, eq.2) is written as follows.

$$S(m,n) = | F(m,n)^2 | /(M\triangle x)(N\triangle y) \quad \text{..........} 3)$$

Where -(M/2-1)$\leqq$m$\leqq$(M/2-1), and -(N/2-1)$\leqq$n$\leqq$(N/2-1). Wave number k, wave length L, wave frequency T, and wave direction α is defined as Fig.3. In this study we use small amplitude wave theory in definition of T vs. wavenumber (m,n).

$$L = (gT^2/2\pi)\tanh(2\pi h/L) \quad \text{.............................} 4)$$

where g is the gravity acceleration, and h is the averaged depth of target area.

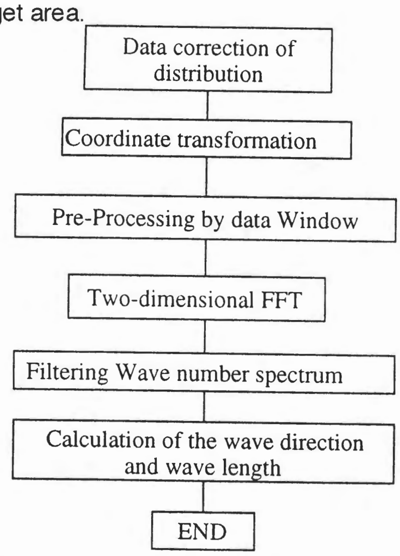


Fig.1 Flow diagram showing the analysis

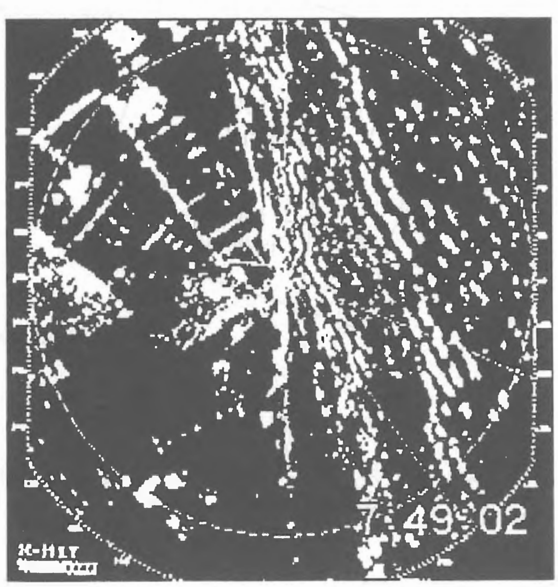
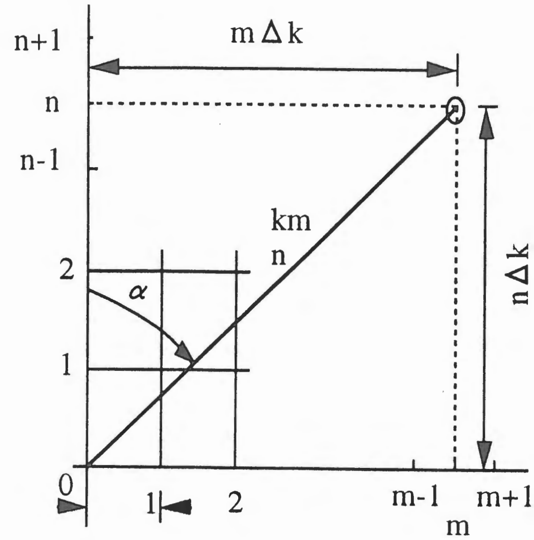


Fig.2 Marine Radar Image



$\Delta k=2\pi/L0$

Wave number :
$k= | \Delta kmn | =2\pi/L$
Wave length :
$L=L0/\sqrt{(m^2+n^2)}$

Frequency :
$T=\sqrt{2\pi L/(g\tanh(2\pi h/L))}$

Wave direction :
$\alpha=\pi/2-\tan^{-1} n/m$

Length of analyzing area : L0
Depth : h

Fig.3 The relationships between wave procedures. number spectrum and wave parameter

2.2 Wave Direction and Wave Speed by Optical Flow Estimation

FFT can detect the macro structure of sea surface, such as the wave direction and the wave length. But the target area of this study is nearshore region. In the nearshore region, the wave phenomena includes the effect the nonliniality such as breaking waves. If the radar echo can show the sea surface structure, the wave speed can be detected by the optical flow from the radar echo. So the the micro structure of the sea surface can be detected by the optical flow model which is sometimes used as the sequential image processing model.
Using the image function : $\rho(x,y,t)$ defined to move with constant spatial distribution, the relationship between the time-spatial incrimination of image function and the velocity of optical flow: $(u,v) = (dx/dt, dy/dt)$ is defined as eq.5). Where x-direction is alongshore direction and y-direction is off shore direction respectively.

$$\frac{\partial \rho}{\partial x} \cdot \frac{dx}{dt} + \frac{\partial \rho}{\partial y} \cdot \frac{dy}{dt} + \frac{\partial \rho}{\partial t} = 0 \quad \text{..........5)}$$

With the assumption, as eq.6), that the optical flow is defined to be constant in locall wave field, the error of each $\rho(x,y,t)$, satisfied by eq.5).

$$\frac{\partial v}{\partial x} = \frac{\partial v}{\partial y} = 0 \quad \text{.......6)}$$

Wave speed of optical flow : u and v, x-direction is yield by using least square method: $\partial E/\partial u=0$, $\partial E/\partial v=0$.

$$E = \sum_i \sum_j \left(\rho_x(i,j,k)u + \rho_y(i,j,k)v + \rho_t(i,j,k)\right)^2 \quad \text{.......7)}$$

$$u = -\frac{1}{\Delta}\left(\sum\sum \rho_y^{\,2} \cdot \sum\sum \rho_t \rho_x - \sum\sum \rho_x \rho_y \cdot \sum\sum \rho_y \rho_t\right) \quad \text{.......8)}$$

$$v = -\frac{1}{\Delta}\left(-\sum\sum \rho_x \rho_y \cdot \sum\sum \rho_t \rho_x + \sum\sum \rho_x^{\,2} \cdot \sum\sum \rho_y \rho_t\right) \quad \text{.......9)}$$

Where Δ is as follows.

$$\Delta = \sum\sum \rho_y^{\,2} \cdot \sum\sum \rho_x^{\,2} - \left(\sum\sum \rho_x \rho_y\right)^2 \quad \text{.......10)}$$

The algorithm used mentioned before is called the "Spatial Local Optimization(SLO) " method[5),6)]. This model is a kind of optical flow model. Fig.4 shows the flow diagram of SLO using radar image.

4. MARINE RADAR OBSERVATION RESULT AND DISCUSSION

The marine radar site was shown in Fig.5 and Fig.6. We observed the target area on Jan.8-11, 1996, when the most highest wave was observed by the wave observational system of in situ data by Ministry of Construction Japan at the same area as Fig.5. The PPI image was converted by A/D convertor and saved into the computer for analysis.

Fig.7 shows the result of comparison between wave direction by marine radar and the in situ data. From this result the wave direction is same as in situ data except the case pre-processed by Hanning window only. Another two case filtered by moving average have good correlation to the observed data.

And Fig.8 shows the result of comparison between wave frequency and in situ data. This shows the frequency observed by marine radar is larger than the data from in situ data.

The error is estimated depending on two reasons as follows. One is the reason that we use small amplitude wave theory on translating from spatial frequency monitored by marine radar to time series frequency. The other is the reason that the radar image includes the shadowing effect of wave surface. Translation from spatial frequency to time series frequency is a big problem on wave theory. But the difference between the frequency from in situ data and the frequency from radar image is too large.

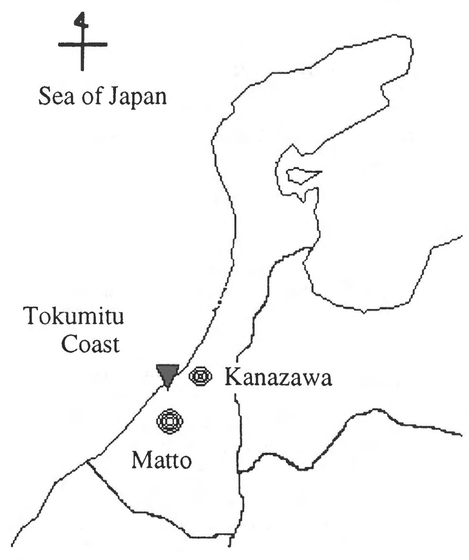


Fig.5 The marine radar site

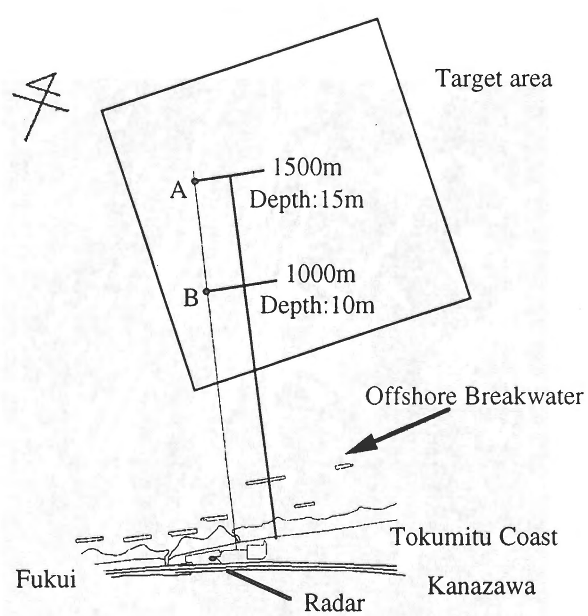


Fig.6 The observational area

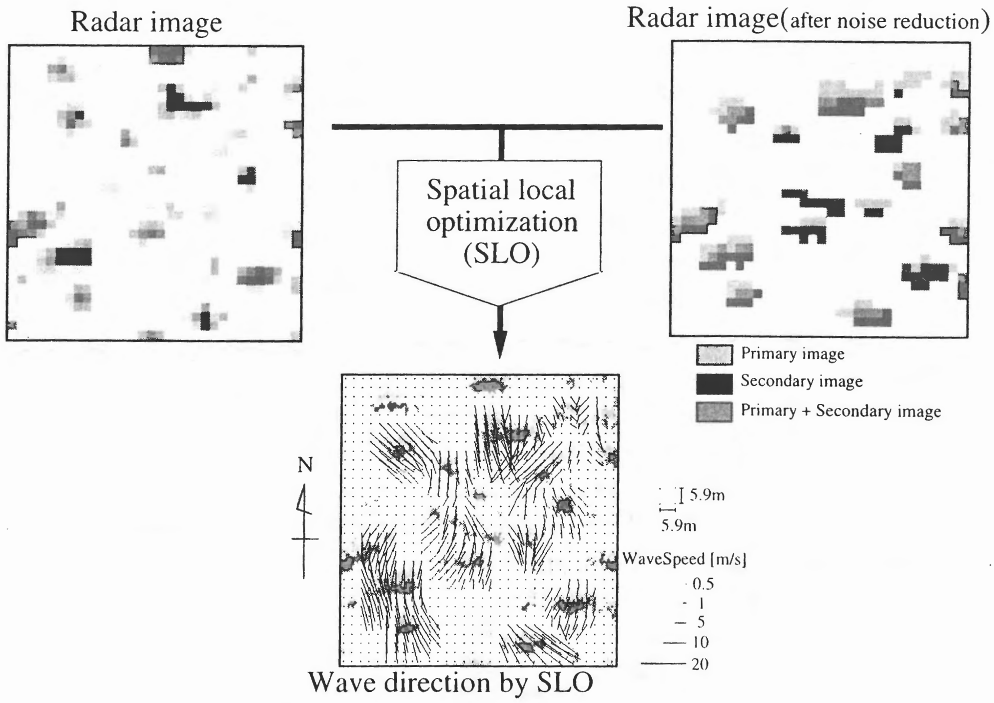


Fig.4 Flow diagram showing SLO method using radar image

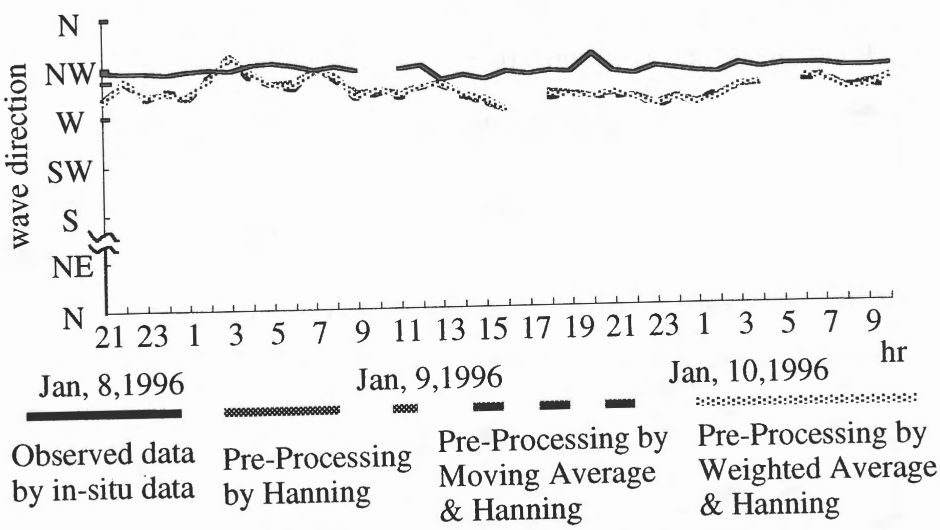


Fig.7 The result of comparison between wave direction by FFT r and in situ data

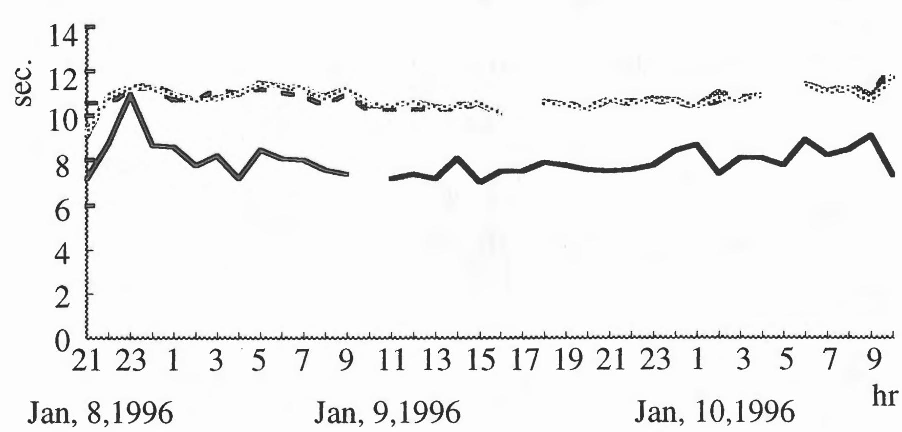


Fig.8 The result of comparison between wave frequency by FFT and in situ data

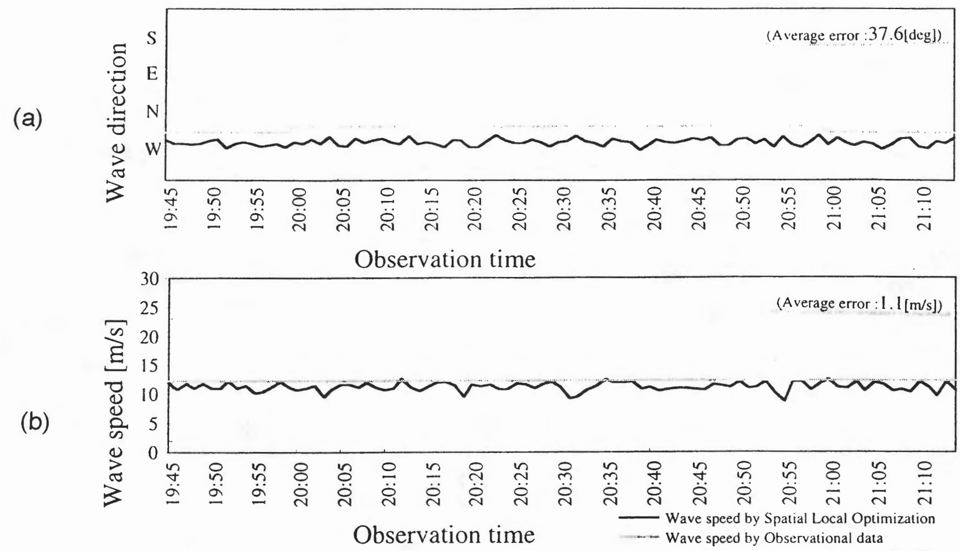


Fig.9 Result of time series of wave direction and wave speed by SLO

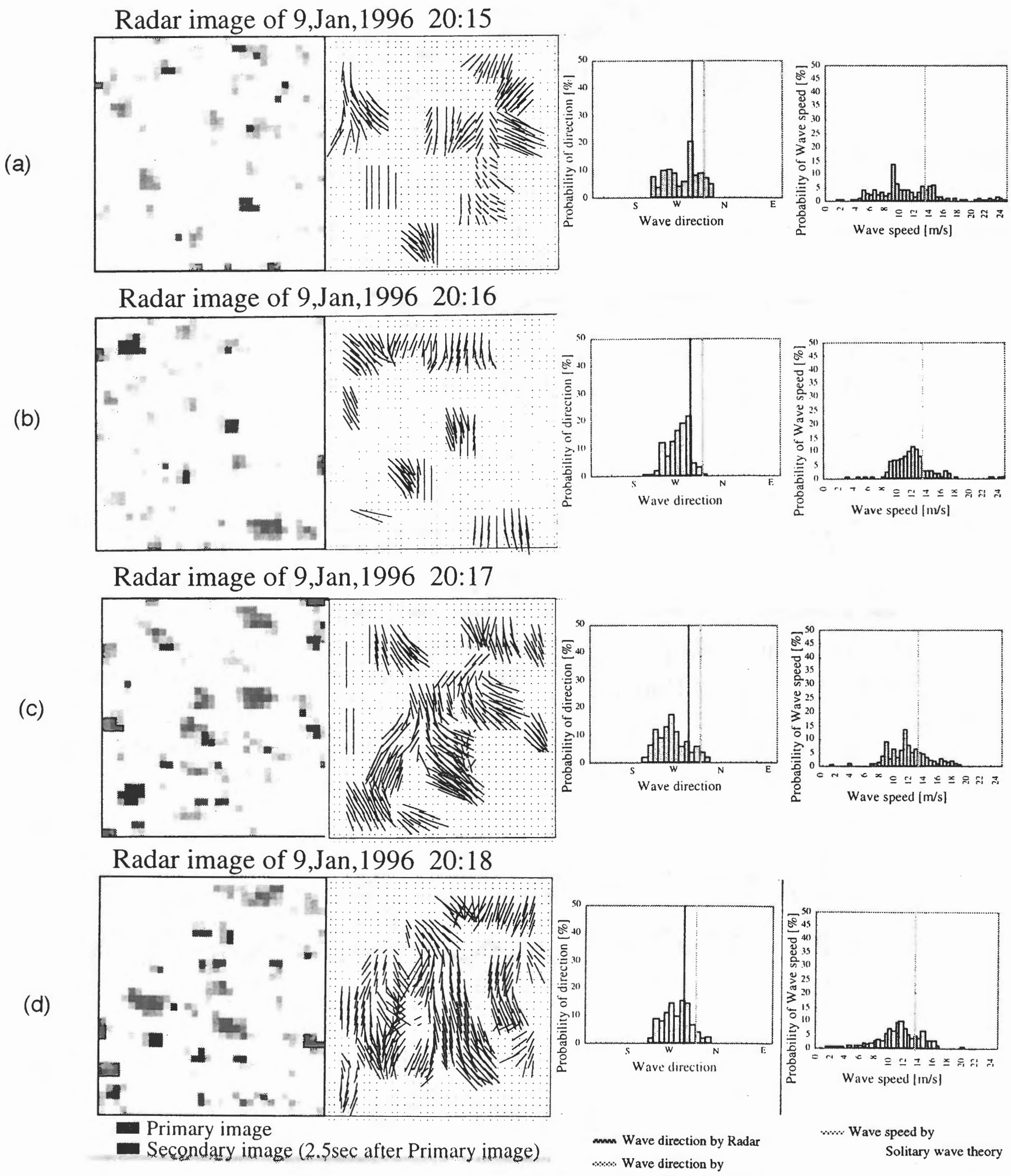


Fig.10 2-D field of wave direction and wave speed by SLO

The FFT analysis of radar image can detect the macro structure of the wave field. And FFT estimates the wave direction and frequency as uniform wave field. So it is difficult to explain the error of radar observation. For estimate the micro structure of wave field, we used the optical flow model as follows.
Fig.9 shows the result of time series wave direction and wave speed by SLO in micro scale. And Fig.10 shows the 2-D field of wave direction and wave speed by SLO method. In Fig.10 the average speed using analytical model, solitary wave model, is used for calibration the result from the result of radar observation.
From Fig.9 SLO using radar image can estimate the wave speed well. But the wave direction is not so good. For explanation of this reason, Fig.11 is used. Fig 11 shows time series of the wave direction and wave height. The circle means the almost wave breaking
point by Goda's wave breaking inception. The average error of the average of wave direction after neglecting the breaking point decreased from 37.6 deg to 35.8 deg.
Fig 9 (c) and (d) show the wave direction field in almost breaking. These image indicate the randomness of the wave surface. This means the breaking wave is effective for estimating the micro structure of wave surface.

6. CONCLUSIONS

The marine radar is effective for observing wave direction and the accuracy is good for operational use. Another wave parameter must be correlated by the corrected radar image considering the shadowing effect.
Wave direction and frequency by FFT is not effective to detect the macro structure of surface wave in nearshore region.
Wave direction and wave speed by optical flow model, SLO, can detect the micro structure of wave parameter, such as wave speed and wave direction in nearshore region. And this model can offer the complements of the FFT image analysis.

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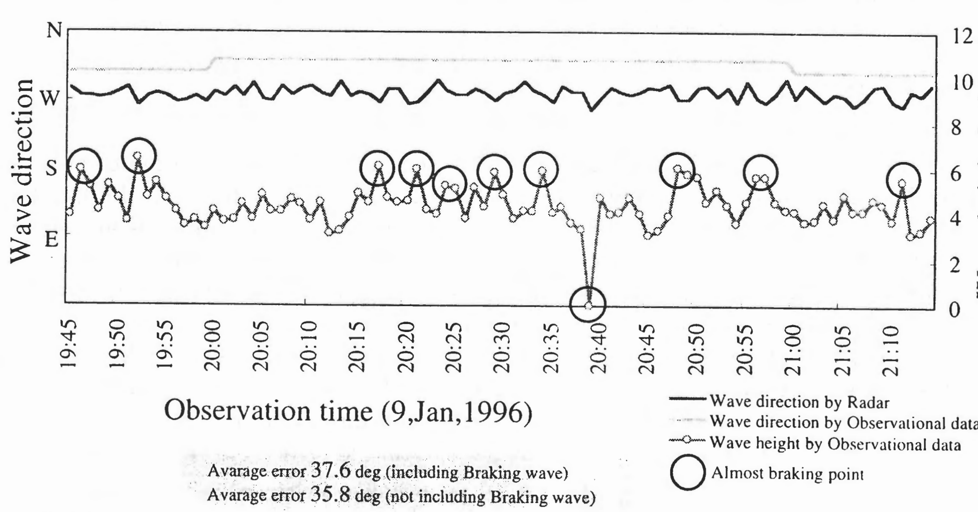

Braking wave inception (Goda)

$$H_b = A\left[1-exp\left\{-1.5\frac{\pi_h}{L_0}(1+15\,tan^{4/3}\beta)\right\}\right]\Big/L_0$$

Fig 11 Time series of the wave direction, wave height and wave breaking inception