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Evaluating Accuracy of Surface Current Vectors Measured by Bistatic HF Ocean Radar

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1. Introduction

High-frequency (HF) ocean radar is a kind of Doppler radar that can monitor ocean surface conditions, such as surface current vectors, wind direction, and ocean waves, by analyzing the frequency of backscattered echoes from the ocean surface. With HF ocean radar, it is possible to continuously observe from land a large area of ocean with less labor, while conventional methods using ships and mooring buoys can only measure at some particular points on the ocean. Therefore, the importance of HF ocean radar is increasing in various fields such as oceanography, coastal engineering, and fishery.

Conventional HF ocean radar is categorized as a monostatic radar whose transmitter and receiver are located in the same place. In the case of bistatic radar, a receiver is located apart from the transmitter. In general, the sensitivity of bistatic radar is inferior in comparison with conventional monostatic radar, and its observation range tends to be smaller. Therefore, bistatic HF ocean radar has drawn little attention, and there have been few cases where surface current measurement using bistatic HF ocean radar were actually done.

In bistatic radar, however, multiple receivers can be stationed for a transmitter, which means that it is easy to construct a multiple-Doppler radar network with fewer transmitters than used in monostatic radar. Having fewer transmitters leads to some remarkable advantages such as lower probability of interference between radars, reduced construction costs, and more efficient use of frequency resources. Another advantage of bistatic radar is that the aperture of either transmitting or receiving antenna can be smaller because it is not necessary for both antennas to produce a narrow beam. Based on these characteristics of bistatic radar, it is expected that bistatic HF ocean radar will be a useful technique to construct a large-scale observation network using many HF ocean radars.

In this paper, we report the results of the simultaneous observation of ocean surface currents using a bistatic HF radar system and drifting buoys performed in the south part of the East China Sea in August 2004 in order to evaluate the accuracy of the surface current vectors measured by the bistatic HF ocean radar developed by the National Institute of Information and Communications Technology (NICT).

2. HF Ocean Radar

Ocean surface measurement using HF ocean radar is based on electromagnetic backscattering from ocean surface waves [1-4]. The HF ocean radar transmits an HF radio wave toward the ocean and receives the signal backscattered by the ocean surface waves. There are typically two prominent peaks in the obtained Doppler spectrum. The peaks are called first-order echoes, and they are due to Bragg resonant scattering by the surface wave components, whose wavelengths are half the radio wavelength and which propagate in the beam direction of the radar. However, the peak positions of the first-order echoes are somewhat different from the expected Bragg frequency that is theoretically determined from a linear dispersion relationship of ocean waves. This difference is caused by the advection of surface waves by ocean currents. Therefore, the radial components of the surface current along the radar beam direction can be derived by

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measuring the frequency shift of first-order echoes from the Bragg frequency. To obtain the spatial distribution of surface current vectors, the radial component of surface currents from more than two radar sites should be combined.

3. Bistatic HF Ocean Radar

The most fundamental bistatic radar system is composed of a master radar and a bistatic receiver. The master radar is conventional monostatic radar. The bistatic receiver does not transmit in itself, and only receives the scattered signal after transmission of the master radar. The general geometry of the bistatic radar observation is shown in Fig. 1. It is assumed that the radio wave that is transmitted from the transmitter at T is scattered once by a target at P and received by a receiver at R. All the scattered signals on the locus of the ellipse whose two foci are at T and R are simultaneously received at the receiver. When the scattering target on the ellipse surface is in motion, the Doppler velocity vector measured at the receiver is oriented perpendicular to the locus of the ellipse. If we assume that the angle between transmitter-target and target-receiver directions equals 2θ (i.e. $\angle TPR=2\theta$, hereafter θ is referred to as bistatic scattering angle), the Doppler velocity measured at the receiver must be multiplied by a factor of $1/\cos\theta$ to obtain the actual Doppler velocity along the direction perpendicular to the ellipse surface [5-8].

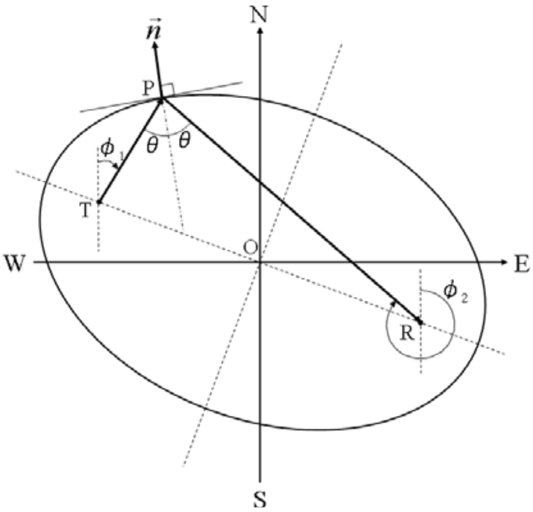

Figure 1: General geometry of the bistatic radar observation

When the transmission frequency is given, the Bragg frequency of conventional monostatic HF ocean radar is uniquely determined. In the case of bistatic HF ocean radar, however, the Bragg frequency changes due to the relative positions of the transmitter, receiver, and scattering point. The measuring depth of the surface current by HF ocean radar is based only on the wavelength of the ocean wave that contributes to the Bragg scattering [4]. Therefore, the bigger the bistatic scattering angle θ becomes, the deeper the measuring depth of the bistatic HF ocean radar becomes.

4. Experiment and Results

NICT developed an HF ocean radar system with the frequency of 9.2 MHz in 2001, and this system was named Long Range Ocean Radar (LROR) [9]. LROR is composed of two HF ocean radars located on Ishigaki Island and Yonaguni Island, which are two islands in the Ryukyu Islands in the southwest part of Japan. Though the two radars on Ishigaki Island and Yonaguni Island are usually operated as two independent monostatic HF ocean radars, they can be operated as a bistatic HF ocean radar system in which one is a master radar, and the other is a bistatic receiver. Either of the two radars can act as master radar, and either can act as bistatic receiver.

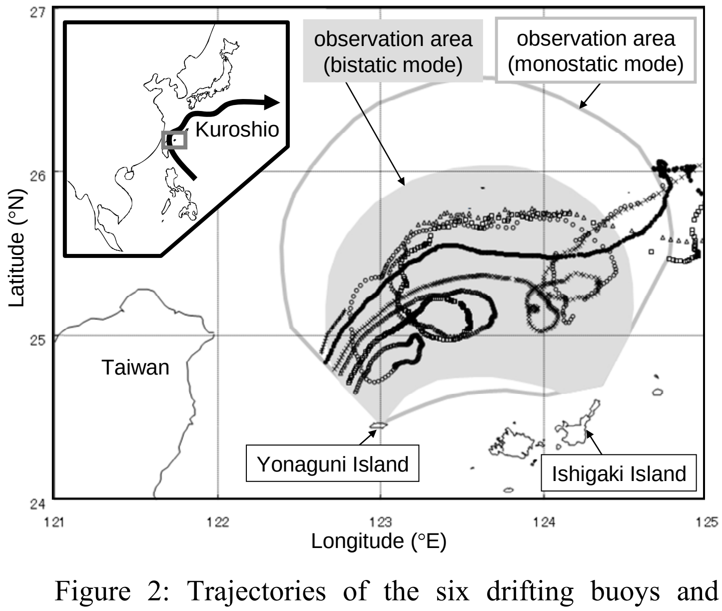

Figure 2: Trajectories of the six drifting buoys and observation area of surface current vectors by Long Range Ocean Radar

Time synchronization between the two radars, which is indispensable for a bistatic radar system, is achieved by using a GPS timing signal.

The simultaneous observation of the ocean surface current by the LROR and drifting buoys was carried out in the south part of the East China Sea in August 2004, in order to evaluate the accuracy of the surface current vectors measured by the bistatic operation mode of the LROR. In this observation, we used six spherical drifting buoys, ZTB-R1, manufactured by Zeni Lite Buoy Co., Ltd. The diameter of the spheres was 30 cm. A drogue was attached to each buoy at a depth of 1.5 m to ensure that the measuring depth of the current vector by the drifting buoys was the same as that of LROR in monostatic operation mode.

Fig. 2 shows the trajectories of the six drifting buoys and the observation area of the surface current vectors by LROR. At first, these buoys flowed northeastward along the flow of the Kuroshio, which is the representative western boundary current. Then the pattern of movement became very complex because of the effects of two typhoons that passed near the area.

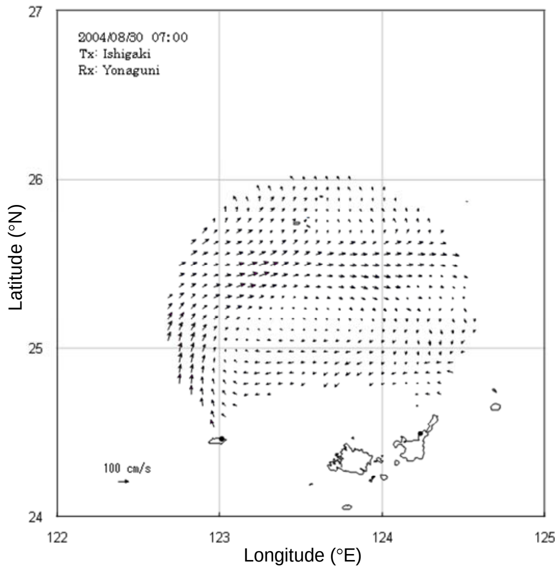

Figure 3: Measured current vectors by the Long Range Ocean Radar in bistatic operation mode at 0700 JST on August 30, 2004

Fig. 3 depicts a sample of the measured current vectors by the LROR in bistatic operation mode at 0700 JST on August 30, 2004. In this case, the radar at Ishigaki Island was operated as master radar, and the radar at Yonaguni Island was bistatic receiver. It is shown that the Kuroshio flowing into the observation area from the southwest gradually turns eastward. The maximum velocity of the measured current was more than 100 cm/s. An eddy-like current is also seen in the center of the observation area. It is consistent with the movement of the drifting buoys shown in Fig. 2.

In Fig. 4, the comparison results between the surface current vectors measured by the LROR and those derived from the drifting buoys are shown. Fig. 4(a) and 4(b) compare the East-

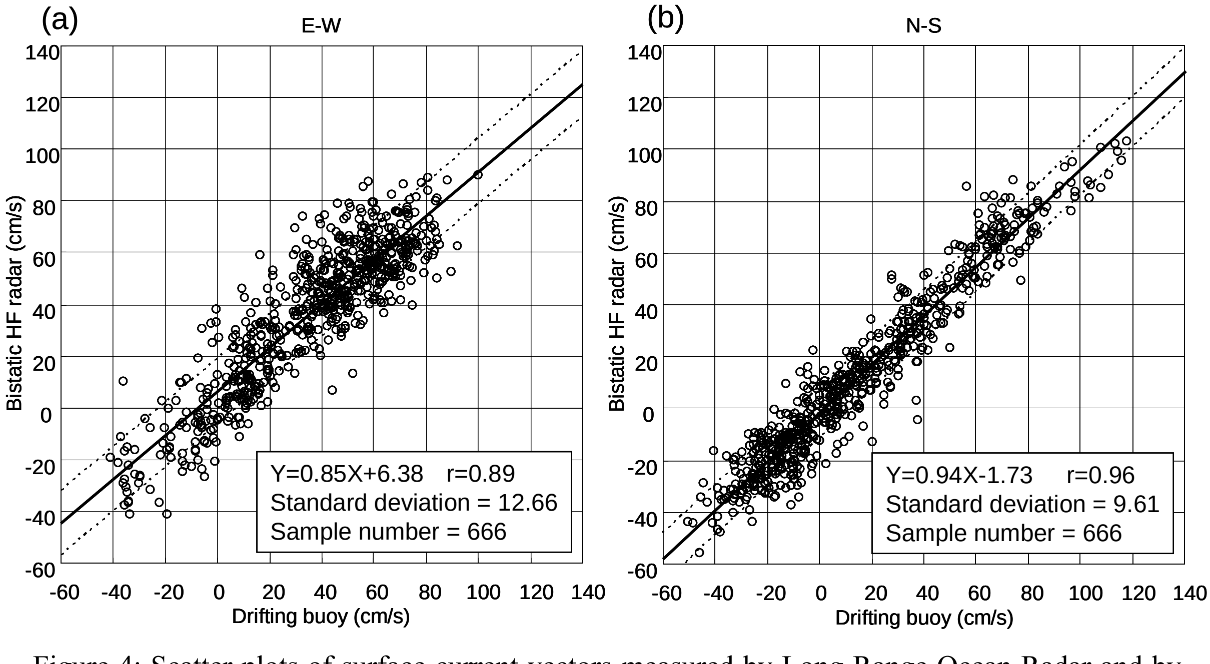

Figure 4: Scatter plots of surface current vectors measured by Long Range Ocean Radar and by drifting buoys. (a) East-West component; (b) North-South component

West and North-South components of the measured current vectors, respectively. Both components measured by the LROR show sufficiently good agreement with those obtained by the drifting buoys. It is not a problem at all practically, but the correspondence of the East-West component between the LROR and the drifting buoys is not quite as good as that of the North-South component. In general, the error that occurs when combining a vector from two radial current components depends on the configuration of the two radar sites [10]. Using LROR, the combining error along the East-West direction becomes bigger than that along the North-South direction, essentially.

5. Summary

To evaluate the accuracy of surface current vectors measured by a bistatic HF ocean radar system, simultaneous measurement using the bistatic HF ocean radar system and drifting buoys was carried out in the south part of the East China Sea. The current vectors measured by the radar are in very good agreement with those measured by the drifting buoys. This indicates that the bistatic HF ocean radar system can measure surface current vectors with sufficient practical accuracy.

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