TRACKING FRESHWATER PLUME USING OCEAN RADAR IN ARIAKE BAY, JAPAN

Takumi Yoshii[1]*, Takaki Tsubono*[1]*, Shin'ichi Sakai*[1]*,*
Masafumi Matsuyama[1]*, Akihide Tada*[2] *and Takehiro Nakamura*[2]

* Central Research Institute of Electric Power Industry, Japan
**Nagasaki University, Japan

1. INTRODUCTION

A freshwater discharge from a river is a crucial factor to understand water circulation and ecological system near the river mouth due to the changes of seawater density and the nutrient supply for the ocean. Therefore, water pollution such as red tide is strongly dependent upon the amount of water discharged from river and the pathways of them. It is clear that there is a need to understand the behavior of the freshwater discharge from rivers in order to predict and prevent the red tide. Remote sensing techniques will offer a useful tool for the measurement compared to the in-situ measurements conducted in most previous field since they provide information over a large span of spatial and temporal scales.

Ocean radar is a useful remote sensing technique for measuring the surface current in ocean with high resolution. In recent years, some field measurements indicate the effect of salinity on the receiving signal intensity (e.g. [1]). However, the detail of the effect is not thoroughly investigated. In this paper, we investigated the effect of salinity on the receiving signal intensity of the ocean radar through the theory and field measurement. Furthermore, we made an attempt to track the freshwater plume from Chikugo River in Ariake Bay using the receiving signal intensities of the ocean radar with VHF band.

2. THEORY

According to [1], the signal intensity of Bragg scattering (S_{rec}) is calculated using the below expression.

$$S_{rec} = \frac{P_t G_t \sigma A_{rec}}{16\pi^4 R^3} A^4 \tag{1}$$

Here, P_{t} is the transmitted power, G_{t} is the antenna's gain, σ is the radar cross section of the water surface, A_{rec} is the effective area of the receiving antenna, R is the distance between the radar station and the scattering point, A is the attenuation factor. All the coefficients are assumed to be constant excluding A and σ. The attenuation factor A depends on the electric conductivity and the permittivity of the underlying water. The salinity changes the electric conductivity of salt water from 0.001 S m^{-1} (freshwater) to 4.0 S m^{-1} (ocean water). The permittivity is independent of salinity. Reducing the electric conductivity leads to increased propagation loss, resulting in the reduction of the receiving signal intensity. On the other hand, σ changes in proportion to the wave spectrum of the half-wavelength to the transmitting radio wave [2]. Therefore, the signal intensity returned from the ocean depends on salinity and the spectrum of scattering wave.

3. OBSERVATION

Observations were made using the ocean radar with VHF band (41.9 MHz) from December 8, 2006 to January 29, 2009 at Ariake Bay, Kyusyu, Japan (Fig. 1). Ariake bay has a great tidal range of ~ 6m at the maximum and huge tidal flats. The flow of Chikugo River located on the northeast of Ariake Bay is a main source of freshwater, and its flow is roughly 30 $m^3 s^{-1}$ under normal condition, up to 5000 $m^3 s^{-1}$ after heavy rainfall in summer. The ocean radars were installed at Unzen and Arao. Wind meters and rain gauges were installed at both observation sites. The salinity and water temperature of 1m depth were measured every 10 minutes with CTD at the mouth of Isahaya Bay from May 23, 2007 to August 7, 2007.

4. RESULTS

At Jul. 7, 2007, the flow of the Chikugo River increased up to 5000 $m^3 s^{-1}$ and supplied a large amount of freshwater in Ariake Bay. The salinity shows a remarkable decrease after that. The first order scattering intensities returned from the point near the CTDs were compared with the salinity (Fig. 2). Fig. 2 shows that as the salinity decreased, the signal intensity decreased. The time variation of the signal intensity was in phase with that of the salinity. These results support the theory that the attenuation of the radio wave increases with decreasing of the surface salinity. This result also implies that the receiving signal intensity of the ocean radar could detect the lower salinity area such as freshwater plume from the river.

Authors calculated the fluctuation of the receiving signal intensities by subtracting the average signal intensity from the measured one at each measuring point within the survey area after the increase in the flow of Chikugo River (Fig. 3). The lower intensity area appeared at the west part of Ariake Bay and spread southward with the same direction as the surface current. Some past literatures (e.g. [3], [4]) indicated that the freshwater plume from Chikugo River travels counterclockwise in Ariake Bay and go southward along the west side of Ariake Bay. The pathway of the lower intensity area coincides with that presented in past literatures. The effect of the variation of the wave spectrum of the scattering wave seems not to be so large because the wind kept enough speed to develop the wave in this term. These results indicate that this spread of the lower signal area shows the freshwater plume.

5. CONCLUSIONS

In this paper, we attempted to observe the freshwater plume using the receiving signal intensity of the ocean radar. It is revealed from the theory of radio wave propagation and the observation results that the signal intensity received by the ocean radar strongly depends on the surface salinity within the survey area and the receiving intensity decrease as the surface salinity decrease. The planner distributions of the receiving signal intensity show the obvious reduced intensity area. The reduced intensity area was interpreted as indicating the freshwater plume from Chikugo River for the reason that the area spread in a parallel direction with the surface current and its pathway was consistent with that reported in literature. This remote sensing technique will provide an attractive tool for visualizing the pathways of freshwater plume from river.

11. REFERENCES

[1] D. Fernandez, L. Meadows, J. Vesecky, C. Teague, J. Paduan, and P. Hansen, “Surface current measurements by HF radar in freshwater lakes,” IEEE Journal of Oceanic Engineering, Institute of Electrical and Electronics Engineers, pp. 458-471, 2000.

[2] D.E. Barrick, “First- order theory and analysis of MF/HF/VHF scatter from the sea,” IEEE Transactions on Antennas and Propagation, AP-20, pp. 2-10, 1972.

[3] M. Tanaka, S. Inagaki, and K. Yamaki, “Numerical simulation of tide and three dimensional flow in Ariake Bay,” Proceedings of Coastal Engineering, JSCE, vol. 49, pp. 406-410, 2002.

[4] T. Matsuno and H. Nakata, “Physical Processes in the Current Fields of Ariake Bay,” Bulletin on Coastal Oceanography, vol. 42, pp. 11-17, 2004.

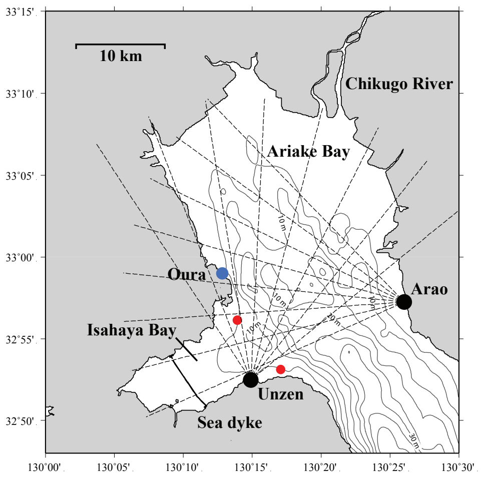

Fig. 1 Observation stations (black circles) and CTD measurement points (red circles).

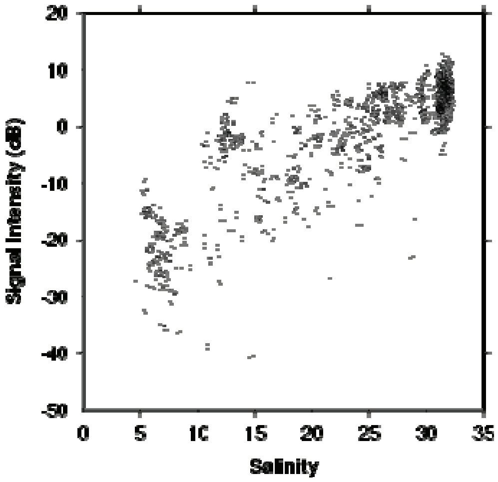

Fig. 2 Signal intensity and Salinity

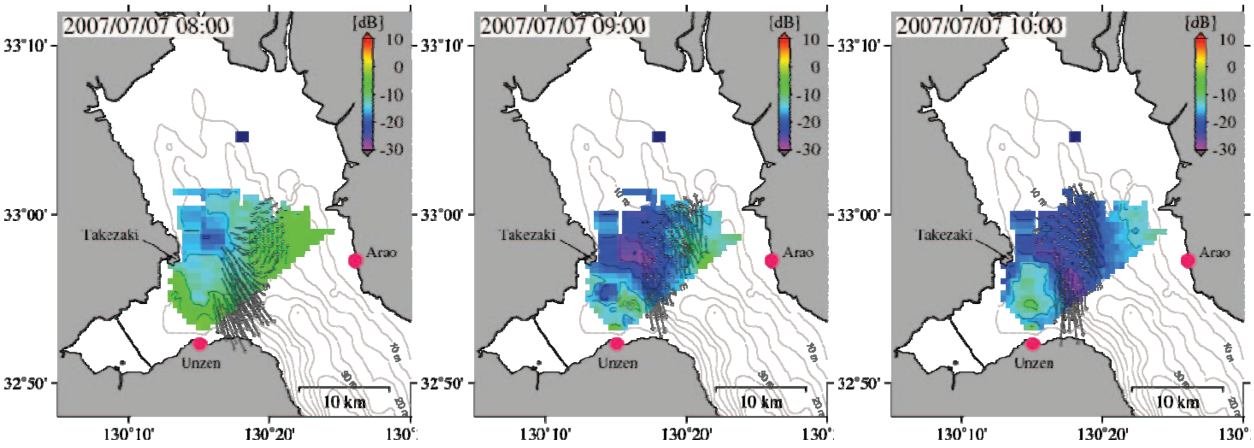

Fig. 3 Planner distributions of the fluctuation of the receiving signal intensity after the increase of flow of Chikugo River