THREE-DIMENSIONAL STRUCTURE OF WIND-DRIVEN CURRENTS ACCOMPANIED WITH SECONDARY CIRCULATIONS AND THEIR EFFECTS ON THE THERMAL STRUCTURE OF LAKES AND OCEANS.

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RESEARCH BACKGROUND

Wind-driven currents “WDC” are one of the important currents in the lakes and ocean, which are caused by the wind. WDC plays an important role in material transport such as an oil spill, the advection of a freshwater mass and phytoplankton, etc. Moreover, it is known that the secondary circulations called the “Langmuir circulations : LCs” are often formed, which have an axis in the downwind direction. Fig.1 shows the schematic diagram of Langmuir circulations. By the mixing of momentum transport due to these circulations , the horizontal velocity profile has the periodic structure with a high-speed area and a low-speed area located alternately. However, frequency of occurrence, detailed characteristics, surface speed, influence of the water mixing on the thermal structure, have not been understood yet.

Weller&Price (1988) observed the three-dimensional structure of wind-driven currents accompanied with secondary circulations by using the very large-scale observation technique called “R.P.Flip.” However, this observation technique is the large-scale and it is impossible to be performed frequently and continuously. In order to clarify the importance and the further detailed character of the WDC accompanied with LCs, it is required to perform the long-term observation frequently, and the simple observation technique is required to be proposed.

RESEARCH PURPOSE

In this research, by using the ultrasonic current profiler of a horizontal type(H-ADCP) and a vertical type(WORKHORSE), it a long-term and highly precise observation system by the simple observation technique was proposed. By using this method, three-dimensional structure of WDC is investigated and detailed characteristics, the formation frequency of these circulations and importance of them on the velocity field were estimated. Furthermore, by using thermometers (thermistor chain), the influence of LCs on water temperature structure of the lake were also discussed.

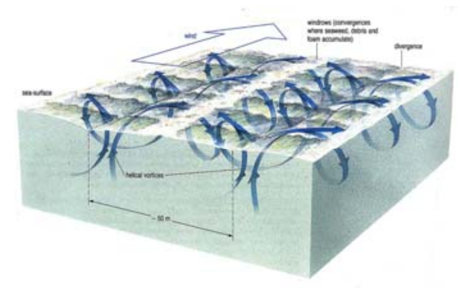

Fig.1 Schematic diagram of wind-driven currents with LCs.(cited from “Ocean currents in ocean circulation” ed. G. Bearman, Pergamon Press).

Fig.2 Aerial photograph of WRB (from Google).

Fig.3 Observed surface streaks.

OBSERVATION OUTLINE

ⅰ) Observation site

Observations were performed at the Watarase retarding basin “WRB”. The aerial photograph of WRB is shown in Fig.2. Since surface waves in the lake are small and the water depth is very shallow, the current meter can be installed easily. Since the mean water level change can be estimated, a current meter is not exposed. Moreover, in this basin, since the difference in the water temperature of the surface and the bottom layer is seen, WRB was selected from these advantages as the observation site.

ⅱ) Details of observation

The main contents of observation is shown as follows : (1) velocity measurement of the WDC by an ultrasonic current profiler. (2) measurement of water temperature change in WRB by a water thermometer. Observations were conducted from September to January in the south block of WRB. During the observation period, the predominant wind direction was the northeast and the northwest. The H-ADCP was set toward the northwest direction and velocity profiles at 90m were obtained in 5m intervals. The WORKHORSE was set to the ship, and observations were conducted by running a ship perpendicularly to wind direction on a windy day. Moreover, the thermistor chains by using water thermometers were set at the point of 110 m away in the northwest direction from the drainage tower which is in a south block of WRB. Variations of vertical profiles of water temperature were observed. Fig.3 shows the streaks suggests the occurrence of secondary circulations which is visible to the lake surface.

OBSERVATION RESULTS AND DISCUSSIONS

ⅰ) velocity profile

Since the velocity profile obtained at the depth of 90cm, the surface velocity profile was calculated by using the formula shown in Equ.1. Fig.4 shows the surface speed of WDC estimated by observation data, the friction coefficient and the logarithmic law proposed by Shemdin (1972). Since the surface speed of the WDC was generally estimated at 3.5% of U_{10}, the red line showed 3.5% of average wind speed 5 m/s at this time. This line shows the middle of the high-speed area and a low-speed area of the surface speed. It is suggested that the value of the surface speed of 3.5% of average wind speed is overestimated in a low-speed area and underestimated in a high-speed area.

$$Us = u(z) + \frac{U_*}{\kappa}\ln\frac{z}{z_0} \qquad U_* = U_{10}\sqrt{\frac{\rho_a}{\rho_w}Cd}$$

u(z)=horizontal velocity, z=90cm、z_0=0.01 by Kato(1975)
U_{10}:wind speed at 10 m =5.0m/s,
friction coefficient Cd=2.60×10−4 by Honda & Mitsuyasu (1980),
κ =0.4 and ρ a=1.225kg/m3, ρ w=1040kg/m3

Equ.1. using some friction and formula proposed by Shemdin(1972).

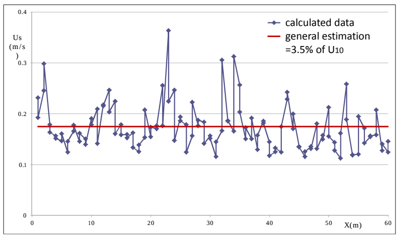

Fig.4 The surface speed of WDC estimated by observational data.

ⅱ)Water temperature profile

The water temperature data obtained by observations were expressed as the time-series at 6 layers. Such diurnal changes were seen during the observed period. Furthermore, the rise of water temperature is decreasing as the depth of layer becomes deep. It can be said that the thermal stratification is formed from the upper layer. Details of these water temperature profiles give us that the water temperature of middle-layer and of bottom layer rises rapidly nevertheless the surface water temperature falls down, and becomes equal to the surface water temperature. This shows that the vertically-uniform condition of water temperature was formed. Fig.5 shows the water temperature data with the wind speed from October 3rd. to October 14th. This figure shows the both cases of the vertically-uniform conditions with the strong wind and the almost no wind. Time series of vertical profile of water temperature from 14:00 to 18:00 on 2011/10/8 at the intervals of 10 minutes was expressed in fig.6. From this figure, we can see the variation from the stratified condition to the uniform condition. Fig.7 shows the relationship between the vertical gradient of water temperature profiles and wind speeds. In this figure, the variation of vertical gradient of thermal profile is taken as the vertical axis and the maximum wind speed is taken as the horizontal axis.

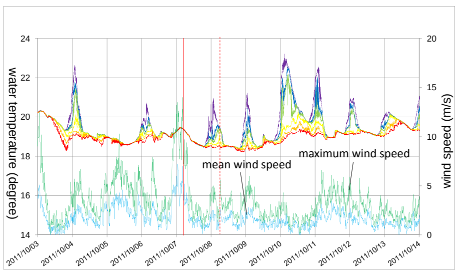

Fig.5 Time series of water temperature at 6 layers and wind speed.

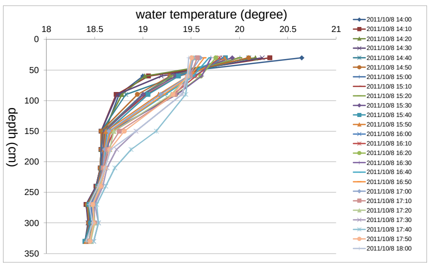

Fig.6 Time series of vertical profile of water temperature.

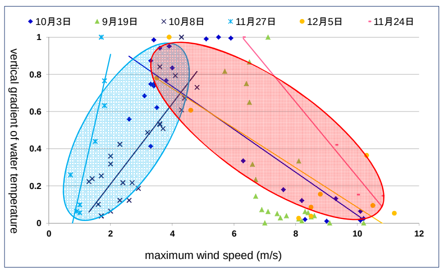

Fig. 7 Relationship between the wind speed and the vertical gradient of water temperature.

CONCLUSIONS

Some of obtained conclusions are shown as follows .

(1) the formation of the streak which suggested the existence of secondary circulations was observed. (2) the spatially-periodic structure of horizontal velocity profile was observed. (3) the maximum surface speed in the high speed area was the twice of the value of 3.5% of wind speed. (4) the variation of water temperature from the stratified condition to the uniform condition was observed. (5) the both cases of the vertically-uniform conditions with the strong wind and the almost no wind were confirmed. The former case is suggested by the water mixing due to secondary circulations formed by strong wind.