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Development of a Current and Water Quality Observation System Using Drift Type DGPS Buoys

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Abstract

A current and water quality observation system consisting of drift type buoys equipped with differential GPS (DGPS) was developed. This report presents the outline of the system that was developed and the results of the verification of the field observations. The system was used to perform current observations along the coast of the Ariake Sea to measure the current and quality of water (salinity concentration and turbidity) carried by the current downstream from a tide gate. The results showed that the system enabled to perform current and water quality observations with accuracy for practical use. The system showed the following characteristics: 1) It enabled to determine easily the path line and the velocity of a surface current; 2) The method was effective for analyzing currents where flowing fresh water converges and where dangerous conditions prevail; 3) The buoys could be equipped with a variety of water quality observation devices; and 4) The risk of observations performed during flooding and under other dangerous conditions could be reduced. The system was found to be effective for performing easily high precision observations of currents and water quality over a wide area extending from river mouths to the open sea.

Discipline: Agricultural engineering
Additional key words: brackish water, salinity concentration, turbidity

Introduction

To design and operate irrigation facilities such as drainage channels and drainage sluices in polder land and low-lying fields as well as coastline conservation facilities such as coastal dikes constructed between the sea and farmland, it is necessary to survey and observe changes in currents and water quality in a wide range of water bodies extending from river mouths to the open sea. Various current and water quality observation methods are already in use. Most of them consist of fixed point observations using towers and similar observation facilities or using moored buoys. The authors developed a system for observing currents and water quality consisting of compact drift type buoys equipped with differential GPS (DGPS).

GPS is a new technology that is now being increasingly applied for various purposes including car navigation, surveying, etc. DGPS is a method for the improvement of the precision of GPS. A reference point with known coordinates (base station) and an unknown point are simultaneously positioned, a receiver at the reference point transmits the error in the measured coordinates to a receiver at the unknown point, and the results of the measurements at the unknown point are corrected by deducting the error from the results of this measurement. Because ordinary users can use DGPS of beacon radio transceiver mode for DGPS positioning measurements without establishing their own base station, they can easily perform high-precision positioning. In Japan, the Maritime Safety Agency began transmitting medium wave beacon radio signals for GPS positioning correction use in 1998.

This report presents an outline of the drift type buoy developed for current and water quality observations in river mouths and along sea coasts and the results of test observations in the field. This new buoy can be used to easily perform high precision observations of a current and of changes in the salinity concentration and turbidity of water carried by the current. It can also increase the safety of workers performing the dangerous task of observing currents during floods and other disasters.

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Fig. 1. Drift type buoy developed for the observation of current and water quality

Outline of the drift type observation buoy

The authors developed a drift type current and water quality observation buoy equipped with a DGPS receiver, personal computer, salinity concentration meter, turbidity meter, a PC card for A/D converter use, and battery as a device to observe currents at river mouths and along sea coasts as well as the quality (turbidity and salinity concentration) of the water carried by these currents (Fig. 1).

As shown in Fig. 2, the buoy's specifications are as follows: diameter, 0.7 m; height, 0.96 m; weight with observation devices, about 54 kg; and draft, 0.68 m. A valve-regulated lead acid battery (rated capacity 40 Ah) installed at the bottom of the buoy can power continuous observations for about 30 h. Three of these buoys have been manufactured. To enhance the precision of positioning by this system, it receives medium wave beacon radio signals provided by the Maritime Safety Agency as correction data for DGPS positioning. The receiver installed on the buoy is AgGPS 132 manufactured by Trimble Co., Ltd. The GPS positioning error possible with single positioning is about 100 m, but only 1 m with DGPS[2]. This system was developed assuming that a positioning precision of 1 m can be used for the observation of currents over wide areas such as brackish water areas. Because the velocity of a drift type buoy is similar to the flow velocity near the surface[1], if the position (longitude and latitude) of a drifting buoy is accurately determined from time to time, it is possible to obtain the velocity and direction of the surface flow and other aspects of the current based on the buoy's changing position. Because the device performs drift type observations, it can be used for observations with the following

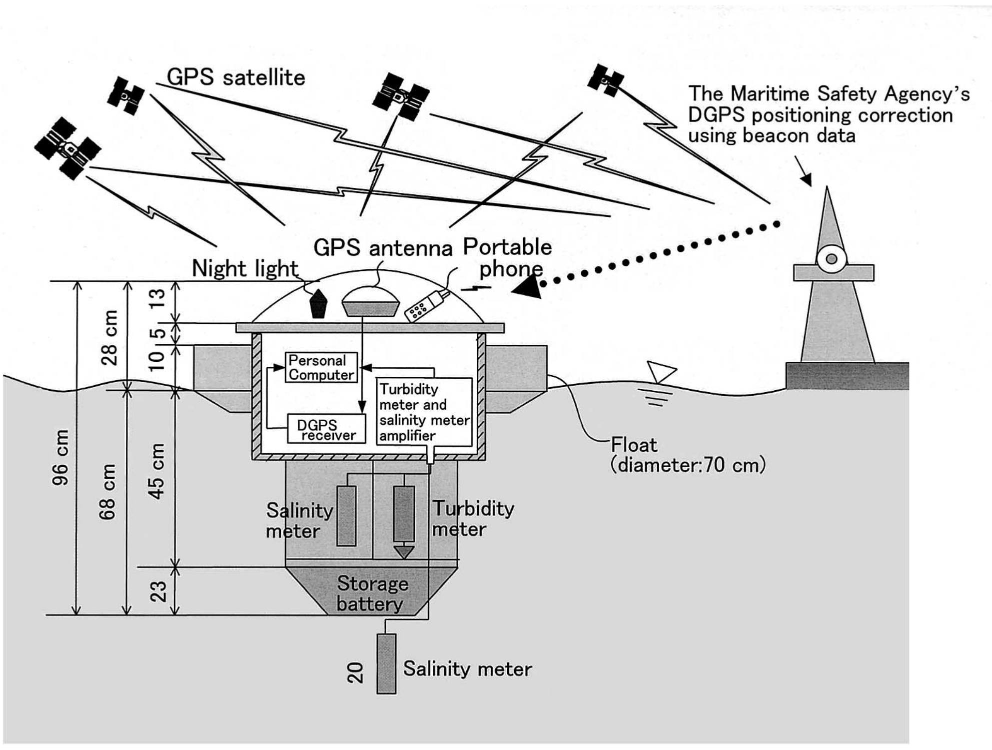

Fig. 2. Specification of buoy for observation of current and water quality

characteristics:

1) When fixed point observations are performed, if the observation network is not dense, it is impossible to obtain accurate stream lines and path lines. However, it is easy to analyze the surface flow with a drift type buoy, because the locus obtained is the path line;
2) The new system eliminates risky observation work, because during a flood period under other dangerous conditions, the buoy is released and the observations are performed unmanned until the buoy is recovered after the flood is over and the current has calmed;
3) Various kinds of water quality observation devices can be installed on the buoy. For the current study, a salinity concentration meter and turbidity meter were installed to measure the changes in the salinity concentration and turbidity in a brackish water area as the buoy drifted with the current. Other kinds of sensors can be installed; and
4) It is an effective way to observe currents such as river mouth density currents where a fresh water current and sea water current converge.

Test observations on land

1) Locus and velocity

An AgGPS 132 receiver was installed in a car that was driven on roads in and around the National Institute of Rural Engineering to test the precision of DGPS positioning. The dark line in Fig. 3 (a) depicts the road that the car traveled inside the National Institute of Rural Engineering. Fig. 3 (b) shows the positions received at 1 s intervals. Circles represent the positions at 30 s intervals. The vehicle was driven inside an adjoining institute from 35 min 30 s to 39 min. The positions received and the positions on the road agreed well.

The AgGPS 132 enabled to calculate the instantaneous velocity by computing the Doppler shift of the carrier wave frequency of the GPS satellite. This method is referred to as the Doppler method. The velocity obtained by this method is referred to as the Doppler velocity in this report. The data fed from the GPS receiver to the personal computer are the output using the NMEA-0183 (National Marine Electronics Association) format that is a standard established mainly for data exchange between maritime equipment and it can be read in through the serial port. The Doppler velocity represents the informa-

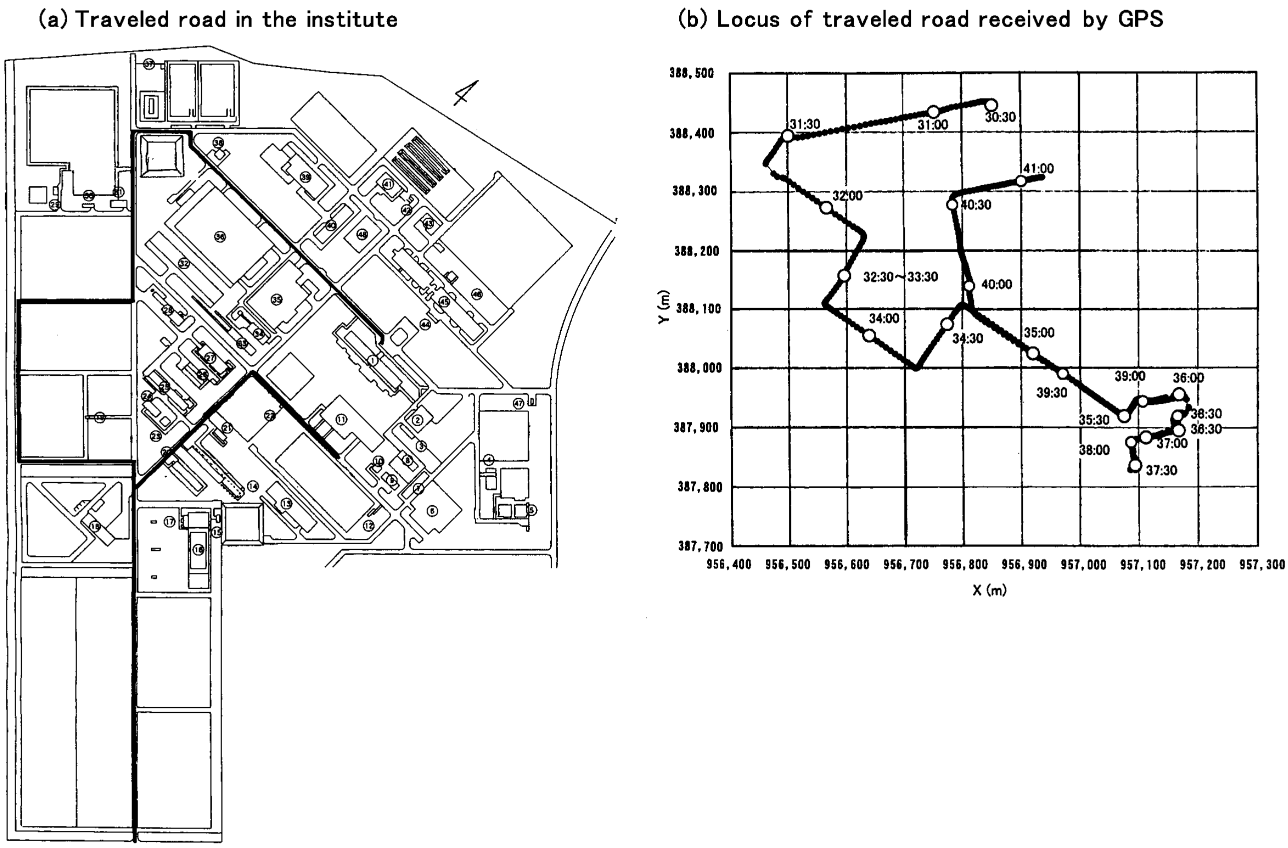

Fig. 3. Comparison of tracks between traveled road and tracks observed by GPS

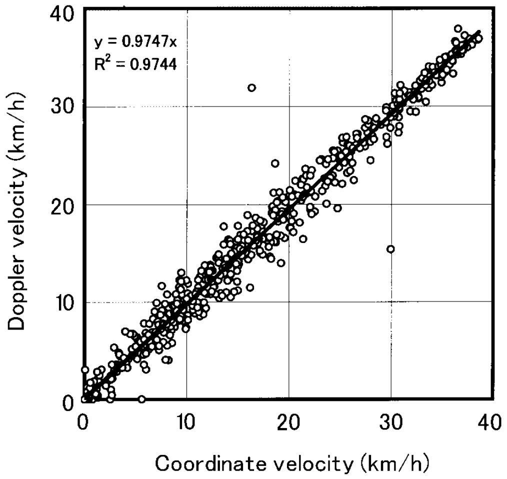

Fig. 4. Relationship between Doppler velocity and coordinate velocity

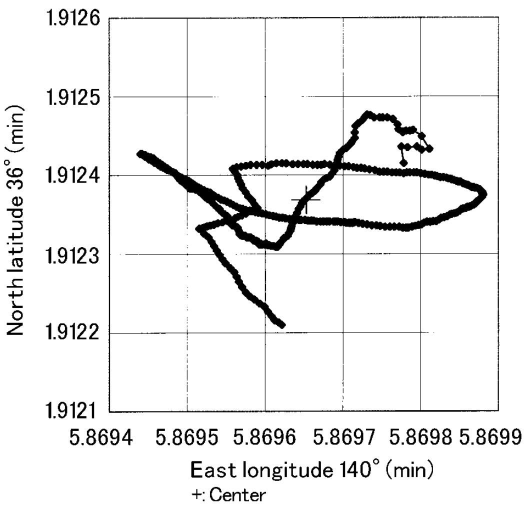

Fig. 5. Changes in received position at the fixed position

tion included in the received data as a single item in an NMEA-0183 sentence.

The velocity obtained from changes in the position coordinates (referred to below as "coordinate velocity") is calculated as shown in the following equation. The velocity is obtained from the changes in the position coordinates (latitude and longitude) measured at times t_i, t_{i+1}. The calculation assumes that 1 min of latitude = 1,850 m and 1 min of longitude = 1,560 m.

$$V_i = \{(1{,}560\,(X_{i+1}-X_i))^2 + (1{,}850\,(Y_{i+1}-Y_i))^2\}^{1/2}/(t_{i+1}-t_i)$$

Where V_i is the coordinate velocity (m/s), X_i, the longitude at time t_i (min) and Y_i, the latitude at time t_i (min). Fig. 4 shows the relationship between the Doppler velocity and the coordinate velocity. A high correlation with a proportion of 0.97 was obtained.

2) Reception

There are 3 GPS quality levels: DGPS positioning, single positioning, and positioning impossible. When beacon correction data cannot be received, single positioning is performed. Single positioning, that is based on the position of the receiver from data received from 4 satellites (3-dimensional coordinates) and by determining 4 unknown numbers of the error of the clock in the receiver, is not as precise as DGPS positioning. During the test run for approximately 15 min, positioning could not be performed 9 times (total of 24 s) because the vehicle passed through the shadow of a building or a thick grove of trees. However, during the rest of the time, DGPS positioning was performed but not single positioning.

3) Positioning precision

Fig. 5 shows the changes in received positions when the vehicle was stopped and its GPS receiver was not moving. The reception duration was 418 s from 15:41:30 until 15:48:28. The "+" symbol in Fig. 5 indicates the center of the received positions (mean value). The positioning error during DGPS positioning is usually assumed to be 1 m, but the standard differential of the positioning error in this period was 0.318 m. Four to 5 satellites were trapped and the PDOP value was 2.2 or 2.3.

Field observations of the current and water quality

1) Observation method

(1) First observations

Verification of observations was performed by placing 3 buoys (A, B, C) on the downstream side of a drainage gate in a sea wall in Harbor I on the Ariake Sea to observe the currents before and after the gate was operated. The observation (buoy drift time) was conducted on the afternoon of August 25, 1998 from 13:50 to 16:30. The buoys A, B, and C were placed at the south end, center, and north end, respectively of the drainage gate. The entire gate is 200 m long with six 33.3 m sluice gates. After the level of the Ariake Sea tide had fallen below the water level in the regulating reservoir, the 6 sluice gates were opened to a maximum of 0.3 m in accordance with operating regulations to measure the currents produced by the water (fresh water) discharged from the regulating reservoir into the Ariake sea. During the observations, the wind speed ranged from 6 m/s to 8 m/s and its direction ranged from south south-west to south-west.

(2) Second observations

Before the second observations, the buoys were modified to observe the water quality as well as the cur-

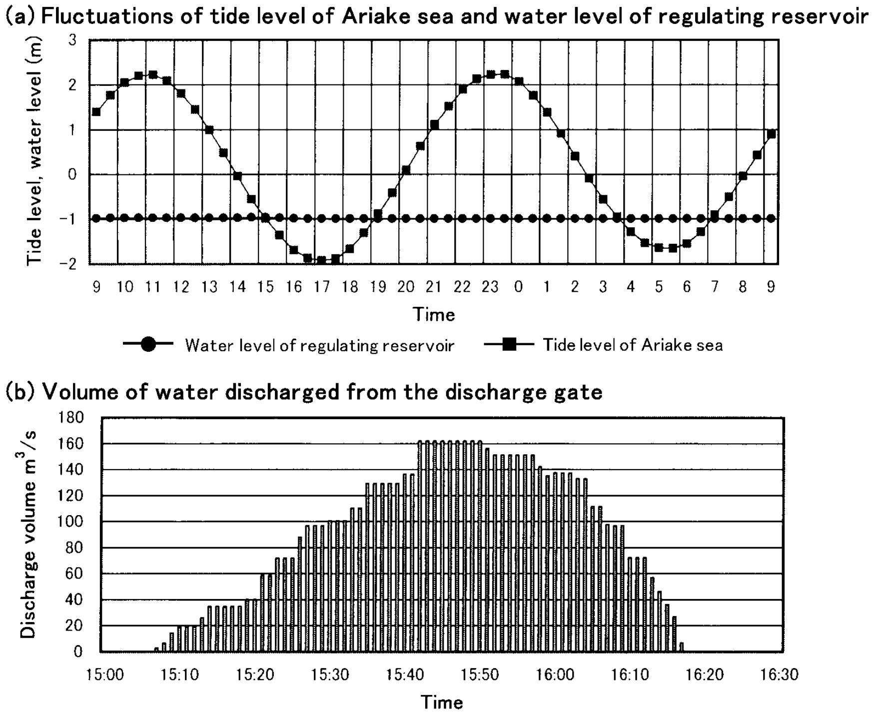

Fig. 6. Tide level of Ariake sea, water level of regulating reservoir and discharge from drainage gate (Aug. 25, 9:00~Aug. 26, 9:00, 1998)

rent. Specifically, they were equipped with turbidity meters and salinity meters. Large storage batteries were installed at their bottoms so that they could be operated for more than 24 h. The current was observed during the discharge of water from the gate in the same way as during the first observations. Three buoys were placed downstream from the sluice gates at the same positions as those during the first observations to observe the current, turbidity, and salinity concentration for 3 h after the gates were opened.

2) Results of the observations

(1) First observations

Fig. 6 (a) shows the tide levels and fluctuations in the water level of the regulating reservoir on the day of the observations. High tide occurred at 10:53 and the high tide level was 2.46 m. Low tide occurred at 17:12 and its level was –1.96 m. The gate was opened for 71 min from 15:07 till 16:17. As shown in Fig. 6 (b), the maximum volume of water flowing from the gate was 162 m^3/s (15:42 to 15:50).

Fig. 7 shows the way that each buoy moved at 60 s intervals. The GPS data were received at 1 s intervals. However, because the flow velocity observed was low, the positions at 60 s intervals are shown. The latitude and longitude received by GPS were the output based on the world geodetic system, but were displayed after conversion to the Tokyo data. Because buoy C drifted close to the shoreline, it was towed southward several times during the observations by a boat so that it would not run aground on the sea bottom. Areas where the plotted positions moved south indicate the locations where the buoy was pulled by the boat.

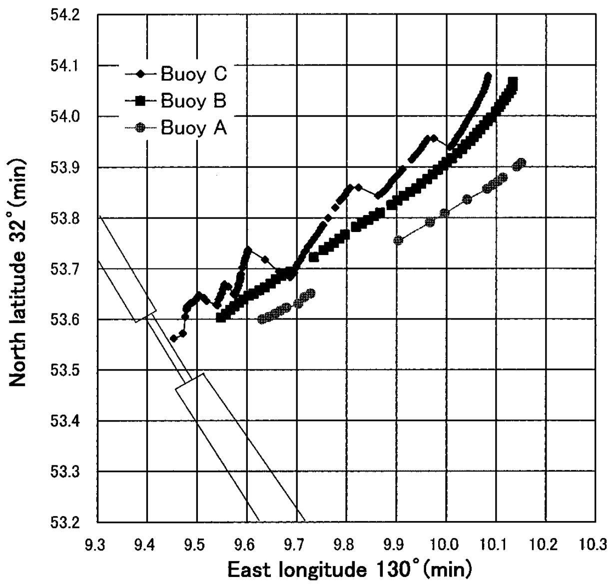

Fig. 7. Locus of buoys after the gate opening (Buoy: A, B, C)

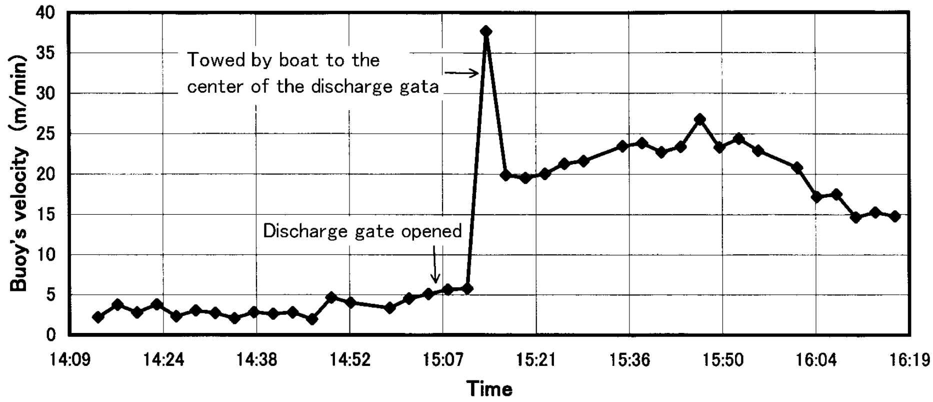

Fig. 8. Changes in buoy's velocity caused by the discharge from the gate

Fig. 8 shows the velocity obtained from changes in the position of buoy B. Before the gate was opened, the principal current was a tidal current caused by the falling tide. The buoy velocity at this time ranged from 3 to 5 m/min. After the gate was opened, the buoy's velocity rose to between 20 and 27 m/min from 15:16, revealing the change in the currents caused by the discharge of water from the regulating reservoir. Afterwards, the drift velocity gradually decreased over time as a consequence of the offshore flow and the last half of the falling tide. Because the water discharged from the regulating reservoir (fresh water) and the sea water could be distinguished by their color, it was confirmed by visual observation of the test that the buoys moved along with and close to the front between the fresh water and the salt water.

(2) Second observations

On the day of the observations, the tide was a spring tide, the high tide occurred at 9:30 and the low tide at 16:18, and the discharge gate was opened for 3 h and 27

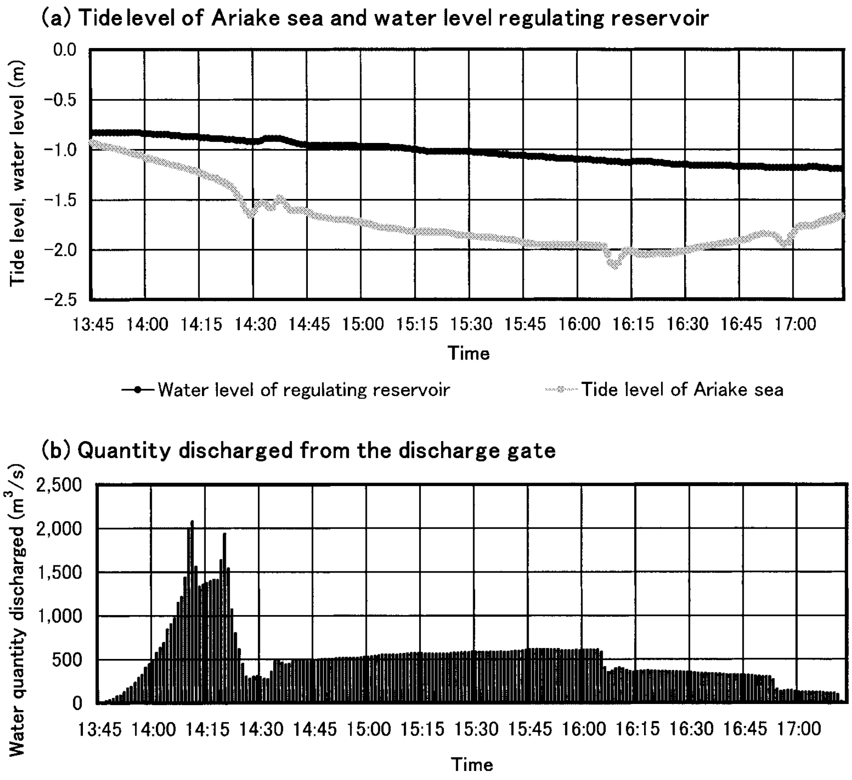

Fig. 9. Fluctuation of tidal level of Ariake sea and water level of regulating reservoir and discharge from gate (Jun 30, 13:45~June 30, 17:15, 1999)

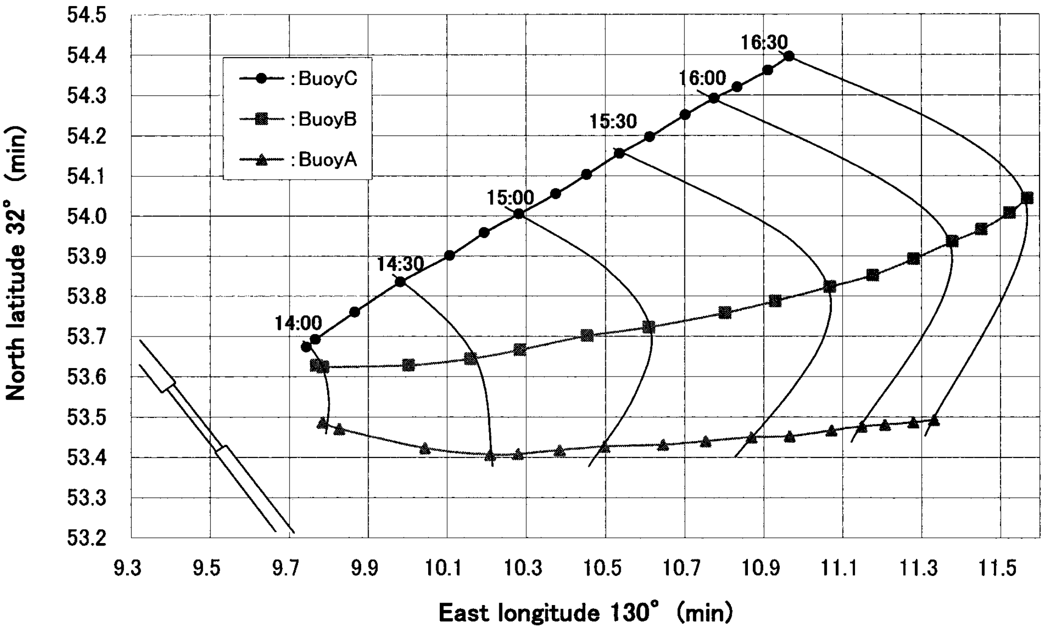

Fig. 10. Location and locus of buoys after gate operation

min from 13:45 until 17:12. In the morning of the day before the observation day, there was a heavy rainfall of 70 mm/h. Fig. 9 (a) shows the changes in the tide level and water level of the regulating reservoir. Fig. 9 (b) shows the discharge rate while the gate was opened during the observation period. A total of 1.06 million m^3 of water was discharged from the sluice gates, lowering the regulating reservoir level by 0.36 m from –0.83 m to –1.19 m.

Fig. 10 shows the locus of the buoy at 10-min intervals measured by the DGPS and the isochrones at 30-min intervals. Buoy C traveled from the gate out to sea in an almost straight line, whereas buoy A and buoy B drifted in the offshore direction while shifting southwards. As the buoys drifted in the offshore direction, the flow velocity decreased. And as explained below, during the second observations, single positioning instead of DGPS positioning may have been performed under the effects of the electromagnetic waves emitted by the instruments inside the buoys, resulting in inadequate positioning precision. The flow velocity of buoy B was the highest, probably because the buoy was located in the middle of the current. The A and C buoys moved at about the same velocity. Visual observation of the buoys revealed that buoy A and buoy B moved close to the boundary between the fresh water and salt water (front) as they drifted out to sea (Fig. 11). During the observation, buoy C slowed as it drifted away from the boundary, presumably because the water close to the shoreline was shallow and its salinity meter (depth of 2 m) touched the bottom. For a little while after they were placed, all 3 buoys moved slowly on the tidal current under the effects of the falling tide, but after the gates were opened and the current of discharged water reached the buoys, their velocity increased as they were carried by this current.

Fig. 11. Shot of buoy B during observations

Fig. 12 shows the turbidity and salinity concentration determined by buoy B. The turbidity was measured at a depth of 0.5 m and the salinity concentration was measured at depths of 0.4 and 2 m. When the fresh water from the gate reached the buoy at 14:05, the turbidity rapidly rose from between 1 and 2 NTU to 120 NTU accompanied by turbulence. As the buoy continued to drift, the turbidity gradually decreased, so that by the time it was

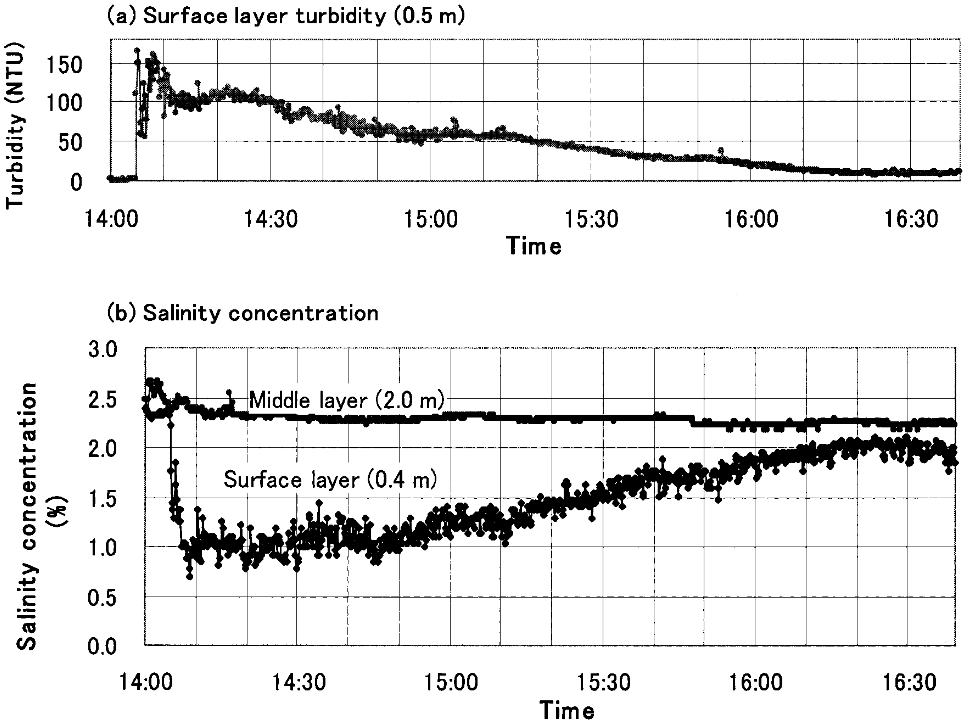

Fig. 12. Fluctuations of turbidity and salinity concentration observed by drifting buoy

removed a little before 17:00, the turbidity was almost identical with the turbidity of the sea water. The buoy drifted along the fresh-salt water boundary, but the turbidity of the surface near this boundary was so high that the change in color at the boundary with the sea water was visible. However, the turbidity at 0.5 m where the turbidity meter was installed was similar to that of the sea water. It can, therefore, be concluded that the turbid layer was extremely thin.

The salinity concentration in the surface layer suddenly fell from 2.3 to 1.0% at the same time that the turbidity abruptly rose, revealing the arrival of the fresh water discharged from the regulating reservoir. Afterwards, it gradually increased so that just before the buoy was removed from the water at 17:00, it had risen to a high concentration of 2.0%, a value lower than the 2.5% value recorded before the sea water converged with the fresh water. The salinity concentration of the middle layer fell abruptly from 2.7 to 2.4% when the fresh water arrived, then gradually declined to finally reach a value of 2.2%. After the low tide at 16:00, it gradually increased until it reached a value of 2.3%.

3) Discussion

(1) Difference in the flow velocity depending on the calculation method

The analysis of the field observation results revealed a wide gap between the Doppler velocity and the coordinate velocity. Fig. 13 shows the relationship between the 2 velocities obtained during the first observations. As stated above, there was a wide gap between the Doppler velocity and the coordinate velocity obtained from the

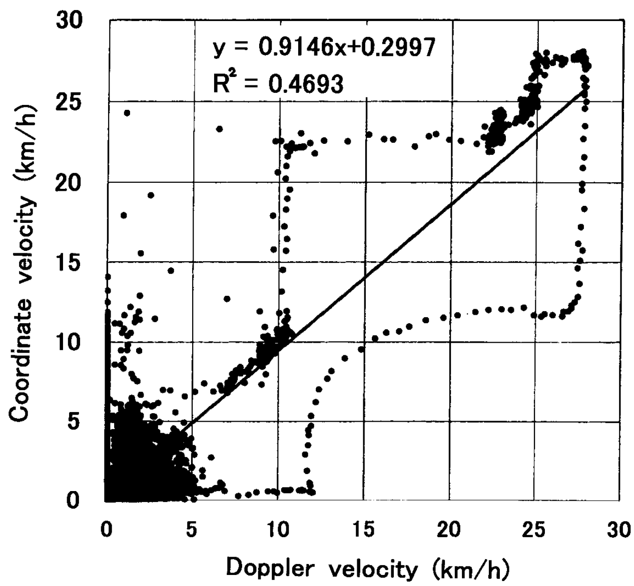

Fig. 13. Relationship between Doppler velocity and coordinate velocity during the first observations of current and water quality

test performed with the positioning equipment on a vehicle. However, it is assumed that when the GPS receivers were installed on the buoys, pitching of the buoy caused by the waves repeatedly accelerated and decelerated the receiver as if it were a pendulum, resulting in a difference between the Doppler velocity and the coordinate velocity, as shown in Fig. 13. Because the observations were performed with the buoys drifting on a wavy ocean surface, the coordinate velocity is assumed to be more accurate than the velocity obtained by the Doppler shift method.

(2) Effects of electromagnetic waves

During the second observations, the positioning was of the single type because DPGS could not be performed. To observe the water quality, a turbidity meter, a salinity concentration meter, and a PC card for AD conversion use were installed inside the buoy. Because the internal devices were close to the GPS antenna, the antenna was influenced by electromagnetic waves emitted by the devices, preventing the reception of the beacon waves. To alleviate this shortcoming, a steel plate was installed as a shield between the antenna and the personal computer to block the electromagnetic waves. Subsequent testing confirmed that this procedure restored beacon reception. During the first observations, both buoy B and buoy C were positioned using the DGPS method, but buoy A was positioned by single positioning from 15:29 to 15:55. At first it was assumed that a GPS problem caused this temporary failure. However, the failure was probably due to the electromagnetic radiation from the personal computer. The results of the first observations were analyzed by eliminating the single positioning data to use only the DGPS positioning data. Because the second observations were performed by single positioning, the positioning results were not as accurate as those obtained by DGPS.

(3) Addition of a present position monitoring function to the buoy

The position data that are received by this system are collected inside the personal computer in each buoy. Consequently, a buoy's position data can only be obtained after the buoy has been recovered. Therefore, when a buoy is lost or positioning data are needed during observations, a monitoring function using a portable telephone could be added to monitor the present position of the buoy. Its functions will be outlined in future.

Conclusion

This newly developed system is considered to be effective for observing currents and water quality over a wide range extending from river mouths to the open sea. In harbors and other water bodies with a wide observation range, a large number of buoys will be needed, but this method can be used for a wide range of observations that cannot be made with a fixed point method, namely obtaining data on water quality along with the movement of a current. The system can only be used for 30 h due to the limitations imposed by the battery capacity. Further studies will be carried out to develop instruments requiring less power and a high capacity battery or a solar cell power system allowing continuous observations lasting up to one week. These changes may improve the system so that it can be used continuously over an even wider range of coastal waters.

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