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Long-term measurement of stream flow and salinity in a tidal river by the use of the fluvial acoustic tomography system

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SUMMARY

Long-term variation of stream flow of a tidal river was measured by an innovative technology, called the fluvial acoustic tomography (FAT). The reciprocal sound transmission was performed between two acoustic stations, located on both sides of the river. Even in the tidal river with the periodic intrusion of salt wedges, the cross-sectional average velocities along the river stream axis, estimated from the travel time difference data, were consistent with the average velocities, observed by an array of moored downward-looking ADCPs. The cross-sectional average salinity was also estimated by using the mean travel time data collected from the reciprocal sound transmission, the mean values of temperature measured by the conductivity–temperature (*C*–*T*) sensors, and the ray simulation result. The derived salinity data from the FAT are comparable with that obtained by the *C*–*T* sensors.

It is concluded that the fluvial acoustic tomography (FAT) is a prospective method for the continuous monitoring of tidal river discharge and temperature/salinity variations.

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1. Introduction

River discharge is an important hydrological factor in river and coastal planning/management and control of water resources. Therefore, it is a key issue to establish the methodology and subsequent technology for measuring stream flow. For continuous measurement of stream flow, a few different methods of instrumentation have been proposed, e.g., acoustic velocity meters (AVMs), horizontal acoustic Doppler current profilers (H-ADCPs), and so on (Catherine and DeRose, 2004; Wang and Huang, 2005). The main drawback of previously proposed methods is that a limited number of velocity sample points are distributed in the cross-section of a river stream, which makes cross-sectional average velocity unreliable. It is difficult to estimate cross-sectional average current velocity in complex flows such as tidal estuaries, or during extreme hydrological events like a flood. In tidal estuaries, the velocity distribution in cross-section is complex and unsteady owing to the intrusion of salt water. As a result, velocities have to be measured at numerous sampling points instantaneously to estimate cross-sectional average velocity accurately. Although several methods to estimate a velocity distribution have been introduced (e.g., by Chiu and Hsu, 2006; Chiu et al., 2005; Maghrebi, 2006), their results are disputable for complicated flow fields as in tidal estuaries with the intrusion of saline water. Thus, an innovative method and/or equipment are still required for continuous high quality measurement of river discharge in tidal estuaries.

In the present study, the fluvial acoustic tomography (FAT) system is proposed as an innovative method to continuously measure the cross-sectional average velocities of tidal rivers, characterized by the intrusion of saline water and the irregular opening of sluice gates. The results of the FAT experiment are compared with those of the ADCP experiment to evaluate the accuracy of the newer FAT.

2. Study area

The Ota River bifurcates into two main branches about 9 km upstream from the mouth as shown in Fig. 1. The upstream border of the tidal compartment in the Ota River estuary is located about 13 km upstream far from the mouth. River flow in this tidal compartment is characterized by the periodic intrusion of salt wedges. The tides are primarily semidiurnal, but mixed with a diurnal component. The tidal range at a spring tide can be as large as 4 m at the mouth. The observation site was located 246 m downstream from

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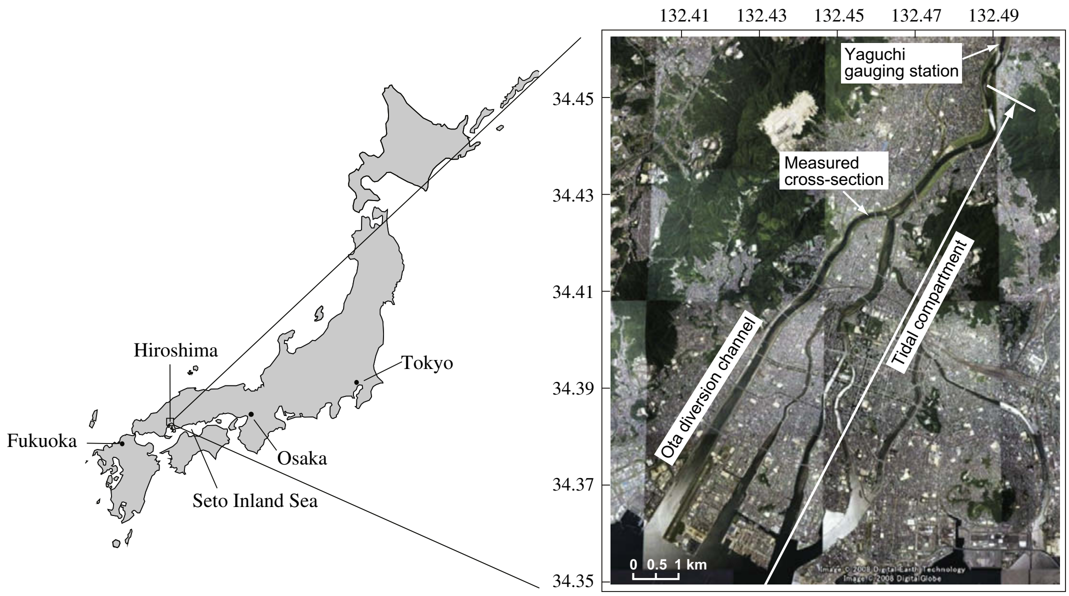

Fig. 1. Study area and experimental site.

the Gion sluice gates near the branched region (Fig. 1). The Ota diversion channel at the observation site is 120 m wide with a bed slope of about 0.04%, and the water depth varies in a range from 0.3 m to 3 m depending on tidal phases. A salt wedge is formed in the ebb tide due to the tidal straining (Simpson et al., 1990).

The freshwater runoff into the diversion channel is usually controlled by the array of Gion sluice gates, located near the bifurcation place. Usually only one sluice gate is opened slightly in order to make the stream cross-section of 32 m × 0.3 m for spilling water. The inflow discharge is about 10–20% of the total flow rate of Ota River in normal days. However, the accurate discharge at the Gion sluice gates is indefinite because the flow is influenced by tidal oscillation and saltwater intrusion. During flood events, all sluice gates are completely opened and the freshwater runoff from the Gion sluice gates is designed to be about half the total river discharge. Since the flow at the Yaguchi gauging station, which is located in 14 km upstream from the mouth, is not tidally modulated, the Ota River discharge before the bifurcation can be estimated by the rating curves. The saline water in this estuary can intrude up to as far as 11 km upstream from the mouth.

3. Method

3.1. Overview of the system

As shown in Fig. 2, in this method a couple of transducers are on both sides of the channel to measure velocity component along the sound transmission line (ray path). The FAT system measures the

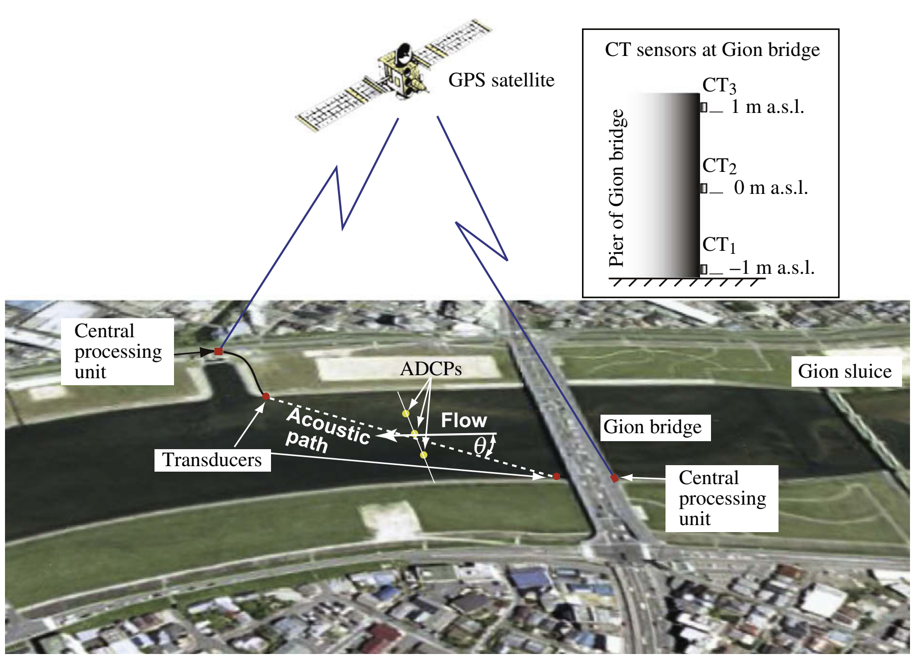

Fig. 2. Aerial view of the experimental set-up.

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