Flood-Discharge Monitoring in a Compound Channel Using H-ADCP Measurements and River-Flow Computation

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ABSTRACT

We present and apply a new discharge monitoring system that uses H-ADCP measurements and numerical simulations to flood-discharge monitoring in a compound channel. In the numerical simulation, we introduce two types of numerical procedures for data assimilation using an additional term F_a and Manning's roughness coefficient *n*, called the dynamic interpolation and extrapolation-*f* (DIEX-*f*) and DIEX-*n* methods, respectively. These methods were applied to flood-discharge monitoring in the middle reach of the Edogawa River. The results indicate that DIEX-*f* and DIEX-*n* methods perform good for discharge monitoring under large flood conditions, showing the applicability of the present method into flood-discharge monitoring in a compound channel.

Keywords: discharge; H-ADCP; DIEX method; river flow; compound channel

1 INTRODUCTION

River discharge monitoring has been widely used in the management of rivers, lakes, and oceans. It is therefore necessary to conduct an automatic and accurate way of monitoring river discharge under various flow conditions, including flood and drought conditions. One promising tool for this is a horizontal acoustic Doppler current profiler (H-ADCP), which can measure a velocity profile at a horizontal line across a channel (Wang & Huang, 2005). Since the H-ADCP mounted at a fixed position cannot measure the velocity distribution over the whole cross section, a primary issue for discharge monitoring with the H-ADCP is how the measured line-velocities are interpolated and extrapolated over a cross section.

To resolve this issue, we have recently presented a new discharge monitoring system with an H-ADCP measurement and river-flow simulation in which a dynamic interpolation and extrapolation (DIEX) method is used to interpolate and extrapolate the measured line-velocities over a cross section with the dynamic principle (Nihei &

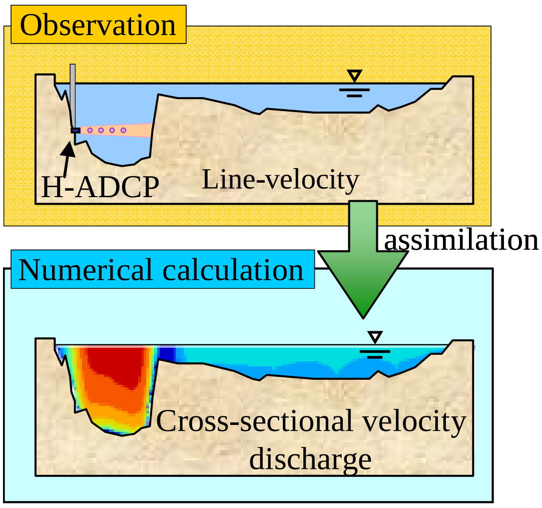


Figure 1. Fundamental structure of present monitoring system

Kimizu, 2008). A new assimilation method was introduced into the DIEX method to assimilate the H-ADCP field data to evaluate the river discharge from the horizontal line-velocities. The fundamental validity of the proposed system was shown through discharge monitoring in the Edogawa River, Japan, only under low-flow conditions.

To further advance our system, we applied it into flood-discharge monitoring in a compound channel. For accurate evaluation of the river discharge, we improved the numerical procedures for data assimilation in the DIEX method. The present system was applied to discharge monitoring in the Edogawa River with a compound channel under high-flow conditions. To check its fundamental performance, the simulated discharge is compared with the results measured with an ADCP.

2 OUTLINE OF THE PRESENT DISCHARGE-MONITORING SYSTEM

2.1 FUNDAMENTAL STRUCTURE

Figure 1 shows a schematic view for the fundamental structure of the present system, which is composed of field observations and numerical simulations. For the field observations, an H-ADCP is mounted at a fixed height to measure the horizontal velocity profile. The 600 kHz H-ADCP (Teledyne RDI) used in this study can collect a velocity profile at a horizontal range of up to 70–100 meters. In the numerical simulations, river-flow computations are performed to interpolate and extrapolate the measured horizontal velocity profile with dynamic principles. Then the velocity distribution over the whole section and discharge can be evaluated. To reflect the observed results in the numerical simulations, we present the DIEX method, which incorporates a data-assimilation technique.

2.2 ORIGINAL DIEX METHOD

For computational efficiency and assimilation of the measured line velocity, a simplified fundamental equation for fluid motion is used in the DIEX method and given as

$$gI+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{1}{D^2}\frac{\partial}{\partial\sigma}\left(A_V\frac{\partial u}{\partial\sigma}\right)-\frac{aC_b}{2}u^2+F_a=0\,, \tag{1}$$

where u is the streamwise velocity, A_H and A_V are the horizontal and vertical eddy viscosities, D is water depth, and a and C_b are the density and drag coefficient of vegetation, respectively. To replace the omitted terms such as advection, diffusion, and unsteady terms, an additional term F_a is introduced into the above equation and used for the data assimilation in which the following depth-averaged momentum equation is solved:

$$gI+\frac{\partial}{\partial y}\left(\overline{A_H}\frac{\partial\bar{u}}{\partial y}\right)-\left(\frac{C_f}{D}+\frac{aC_b}{2}\right)\bar{u}^2+\overline{F_a}=0\,, \tag{2}$$

where $\bar{u}$ is the depth-averaged streamwise velocity, $\overline{A_H}$ is the depth-averaged horizontal eddy viscosity, $\overline{F_a}$ is the depth-averaged added term, and C_f is the coefficient of the bottom friction. Although the additional term in the profiling range of the H-ADCP is calculated by solving Eq. 2, an extrapolation technique of the additional term is used to evaluate the additional term outside the range in the cross section. In the latter case shown in **Fig. 1**, the numerical accuracy of the DIEX method is appreciably dependent on the extrapolation technique of the additional term. Therefore it is necessary to improve the assimilation technique in the DIEX method using Eq. 2.

2.3 IMPROVED DIEX METHOD

To improve the data assimilation in the DIEX method, we use Manning's coefficient *n*, which has a well-known physical background, instead of the additional term. The fundamental change to the equation is removal of the added term from Eq. 1, expressed as

$$gI+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{1}{D^2}\frac{\partial}{\partial\sigma}\left(A_V\frac{\partial u}{\partial\sigma}\right)-\frac{aC_b}{2}u^2=0\,. \tag{3}$$

Instead of Eq. 3, the data assimilation is performed using the depth-averaged equation, given as

$$n=\sqrt{\frac{D^{\frac{4}{3}}}{g\bar{u}^2}\left(gI+\frac{\partial}{\partial y}\left(\overline{A_H}\frac{\partial\bar{u}}{\partial y}\right)-\frac{aC_b}{2}\bar{u}^2\right)}\,. \tag{4}$$

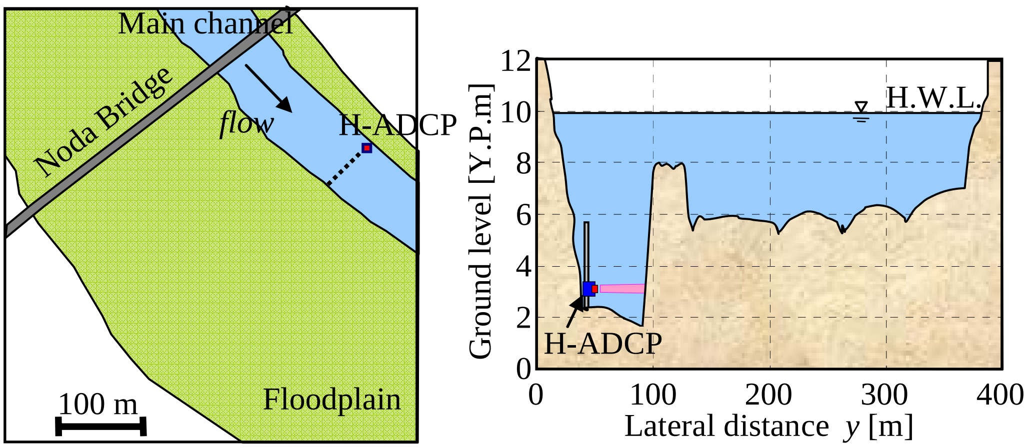
Since the improved DIEX method based on Eqs. 3 and 4 introduces Manning's coefficient *n* for data assimilation, this method is called the DIEX-*n* method. In contrast, the original DIEX method, in which the additional term F_a is used as the assimilated approach, is referred to here as the DIEX-*f* method (Nihei & Kimizu, 2008).

3 APPLICATION OF DIEX-*f* AND DIEX-*n* METHODS TO FLOOD-DISCHARGE MONITORING IN A COMPOUND CHANNEL

3.1 Field measurement

For continuous discharge monitoring, an H-ADCP (Workhorse 600 kHz, Teledyne RD Instruments) has been mounted in the middle reach of the Edogawa River flowing near Tokyo, Japan, from June 2006. The measurement cross-section is a compound channel, as shown in **Figs. 2(a)** and **(b)**. The width of the main channel is one fourth that of whole cross section. Since the measuring height of the mounted H-ADCP is lower than the ground level of the floodplains, the measuring range is limited to the main channel. The H-ADCP was set at a 10-min sampling interval, the blank distance was 1.0 m, and the cell size and number of cells were 0.5m and 100, respectively. We have also installed an optical-type turbidity sensor (Compact-CLW, JFE ALEC) to check measurement accuracy of the H-ADCP under high turbidity conditions.

Figure 3 shows the temporal sequence of the water elevation from June 2006 to April 2008. The arrows in **Fig. 3** indicate two flooding events in which dominant flood flows occurred on the floodplains. To obtain the reference data of river discharge, a 1200 kHz ADCP (Teledyne RDI) was used to measure the velocity distribution and discharge at the Noda bridge which is located 200 m upstream from the cross section of the H-ADCP measurement as shown in **Fig. 2 (a)**. In the measure-



(a) Map **(b)**Cross-section

Figure 2. Outline of the field site

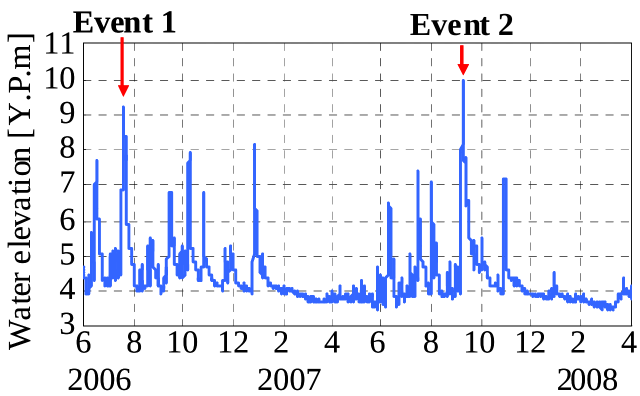


Figure 3. Temporal sequence of water elevations

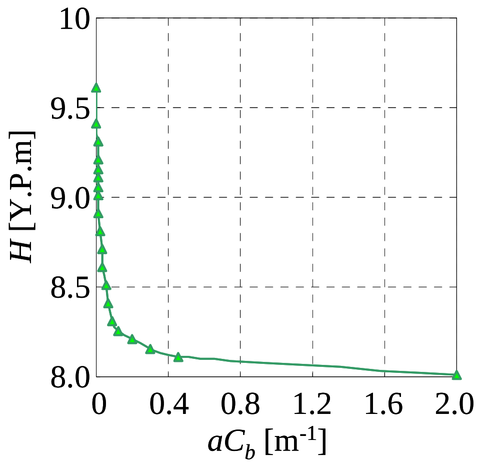


Figure 4. Treatment of vegetation parameter aC_b in the numerical simulation

ments, the ADCP was transected in the lateral direction to obtain the cross-sectional velocity and discharge (Gordon, 1989). The discharge evaluated with the proposed system was compared with that measured by the ADCP to validate the performance of the proposed system.

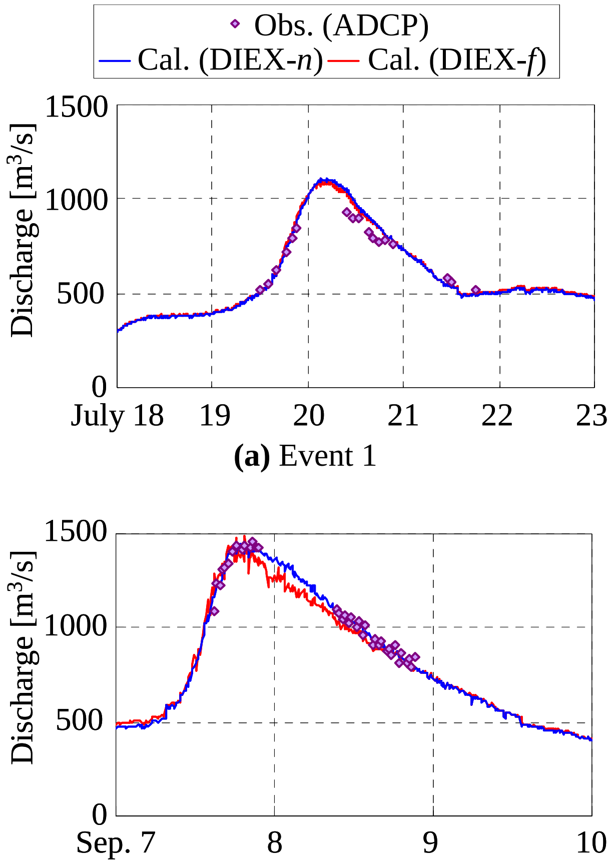
3.2 Computational conditions

In this study, we applied the DIEX-*f* and DIEX-*n* methods to monitor the discharge at the Edogawa River. The computational domain is the whole cross-section, mounted by the H-ADCP, which includes both the main channel and floodplains. Grid size and number in the lateral direction are 0.5 m and 825, respectively. The number of grids in the vertical direction is 100. The vegetation parameters, such as density and drag coefficient of vegetation a and C_b are given as a function of water level, shown in **Fig. 4**, through the reference of the ADCP-measured discharge. Manning's coefficient in the DIEX-*f* method is set at 0.035 and 0.041 $m^{-1/3}s$ in the main channel and the floodplains, respectively. On the other hand, in the DIEX-*n* method, the Manning coefficient is calculated in the main channel although 0.041 $m^{-1/3}s$ is given at the floodplains.

The measurement range of the H-ADCP may be reduced due to appreciable attenuation of acoustic beams under high turbidity conditions that appear in flood events. Therefore we change the range of data assimilation using the lateral profile of echo intensity.

3.3 Results and discussion

Figure 5 indicates the temporal variations of river discharge calculated with the DIEX-*f* and DIEX-*n* methods, Q_{cal}, in two flood events. The discharge measured by the ADCP, Q_{obs}, is also shown in the figure. In event 1, the results calculated with the DIEX-*n* method are almost in agreement with in those with the DIEX-*f* method. Both of the calculated results in event 1 show acceptable agreement with the observed results except during the falling stage. In contrast, in event 2, in which the



(b) Event 2

Figure 5. Temporal variation for discharge in two flood events

peak discharge was larger than that in event 1, both of the calculated results have good agreement with the observed results.

To validate the numerical accuracy of each method in detail, **Fig. 6** depicts the correlation between the calculated and observed discharges, Q_{cal} and Q_{obs}, in events 1 and 2. To explicitly indicate the difference between Q_{obs} and Q_{cal}, 0% and 10% of the relative errors are displayed with solid and broken lines, respectively. The results illustrate that both of the calculated results are almost the same as those of the observed data, and the relative error of all calculated results is less than 10%. The root mean square (RMS) values of the relative error for the results calculated with the DIEX-*f* and DIEX-*n* methods are 5.0 % and 4.4 %. These facts demonstrate that the present monitoring system achieves high performance for the continuous monitoring of flood discharge in the compound channel. The numerical accuracy of the DIEX-*n* method was slightly better than that of the DIEX-*f* method in flooding events, showing the better performance of the DIEX-*n* method.

4 CONCLUSIONS

In this study, we applied the proposed system with H-ADCP measurement and numerical simulation to flood-discharge monitoring in the compound channel to fur-

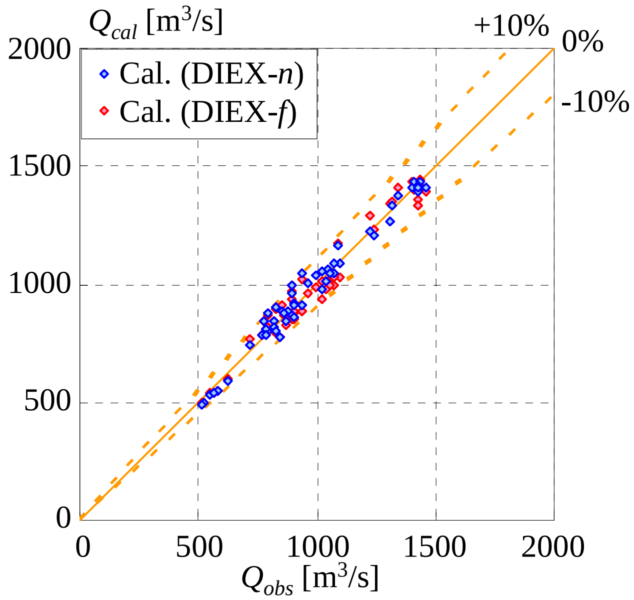


Figure 6. Comparison of the observed discharge Q_{obs} and calculated discharge Q_{cal} in events 1 and 2 for all.

ther advance the system we are developing. In simulations, we introduced two numerical procedures for data assimilation using an additional term F_a and Manning's roughness coefficient *n*, called the DIEX-*f* and DIEX-*n* methods, respectively.

The proposed system was applied to the discharge monitoring in the Edogawa River at a compound channel under high-flow conditions. The results indicate that both of the two methods perform well for discharge monitoring under large flood conditions, showing its applicability to flood-discharge monitoring in compound channels. The numerical accuracy of the DIEX-*n* method was found to be slightly better than that of the DIEX-*f* method in flooding events.

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