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Tidal flow in riverine-type mangroves

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Abstract

The behavior of tidal flow in the riverine-forest type is investigated in the Aira-River mangrove area in Iriomote Island, Japan. In the mangrove swamp near the bank of the creek, a velocity component parallel to a tidal creek reduces greatly in the direction perpendicular to the creek. Based on this finding, it is theoretically suggested that the eddy viscosity in the mangrove swamp, which is caused by the interaction between mangrove vegetation and the shear stress resulting from the tidal flow in the creek, plays an important role in the hydrodynamics of the mangrove swamp.

Introduction

It is important to analyze the hydrodynamics in mangrove swamps from the viewpoint not only of their peculiar physical processes but also of their roles in ecological processes (Wolanski et al. 1980; Wolanski et al. 1992; Mazda et al. 1997a; Mazda et al. 1999; Mazda et al. 2002). Cintron and Novelli (1984) have classified mangrove areas into three types: the riverine forest type (R-type), the fringe forest type (F-type), and the basin forest type (B-type). The water flow in the R-type mangrove area, which is composed of one or more tidal creeks and fringed mangrove swamps, is caused by a tidal action (Mazda et al. 1997b). The tidal flow in the swamp in the R-type has two components: one inundates into the mangrove swamps and the other is dragged by the tidal current in the creek. The former has been studied by Mazda et al. (1997b), but a study of the latter has hardly been undertaken. For example, Wolanski et al. (1980) has shown that the momentum supplied by tidal flow in a creek reduces within a few meters of the bank of the creek due to the eddy viscosity resulting from mangrove vegetation. However, their idea is based on their qualitative experiences and not on quantitative field observations.

In this paper, the authors first introduce a quantitative actual fact of the tidal flow in an R-type mangrove area, and then suggest the importance of the hydraulic resistance of mangrove vegetation to determine the flow pattern in mangrove swamps.

Study area

The field of this study, the Aira-River mangrove area, is in Iriomote Island, the southernmost part of Japan (Figure 1). The Aira-River mangrove area belongs to the R-type. A bottom floor in the swamp is almost flat and the slope is approximately 4.0/1000. The swamp is approximately 100-m in width. The dominant mangrove species in the swamp are *Bruguiera gymnorrhiza* and *Rhizophora stylosa* (Kobashi 2001).

Observation and results

Figure 1 shows an observation line in the Aira-River mangrove area. Current velocities (ACM8M type and compact-EM type electromagnetic current meters; Alec Electronic Co., Ltd.) and water levels (RMD type water level gauge; Rigosha Co., Ltd.) were placed at several points along the observation line perpendicular to the creek. Vegetation conditions and bottom topographies were measured in two periods, from 30 July to 8 August and from 13 to 17 October 2000. The measuring methods were similar to those of Mazda et al. (1997b).

Figure 2 shows an example of the velocity vectors on the observation line with a 25-min interval for a single tidal period. This reveals that the velocity runs parallel at the bank of the creek, and declines at the inner part of the swamp. The magnitude of the velocity decreases with increase of the distance between an observation point and the bank of the creek as mentioned by Wolanski et al. (1980), though the reduction is not within a few meters of the bank of the creek.

Discussion

Tidal flow pattern in the swamp

The flow pattern shown in Figure 2 suggests a hydraulic mechanism such as the water in the swamp is dragged by the tidal flow in the creek and the velocity component parallel to the creek reduces owing to the shear stress, or the eddy viscosity resulting from mangrove vegetation, as pointed out by Wolanski et al. (1980). Considering that the submerged portion of mangrove vegetation and their prop roots that cause flow resistance vary with the tidal phases, the rate of the flow reduction may depend not only on the vegetation density of mangroves and their vertical structures but also on the tidal magnitude.

The gradual change in the flow direction in the swamp implies that the flow does not move simply back and forth alternately at flood and ebb tides, but forms horizontal water circulation in the entire swamp. This velocity distribution and its tidal variation are likely to play an important role in the water quality, the soil

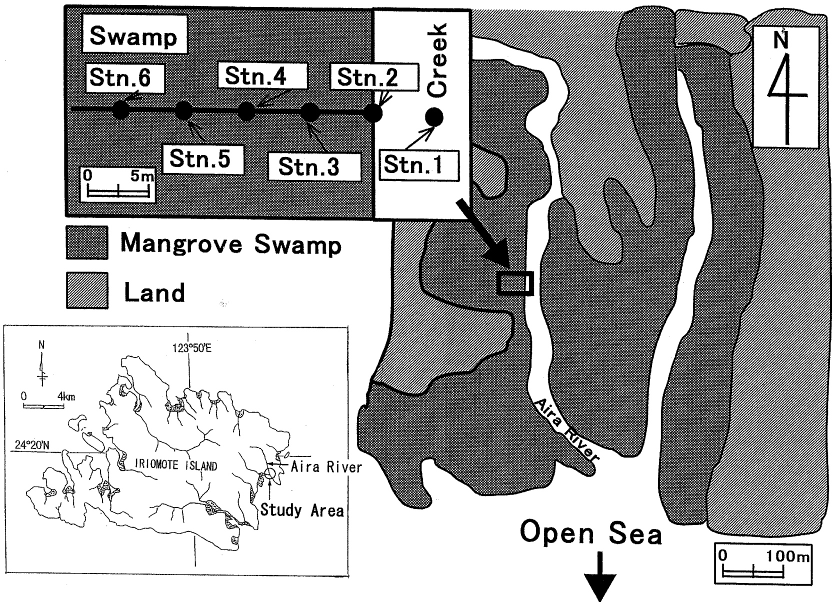

Figure 1. Location map and study area of the Aira-River mangrove area, Iriomote Island, Japan.

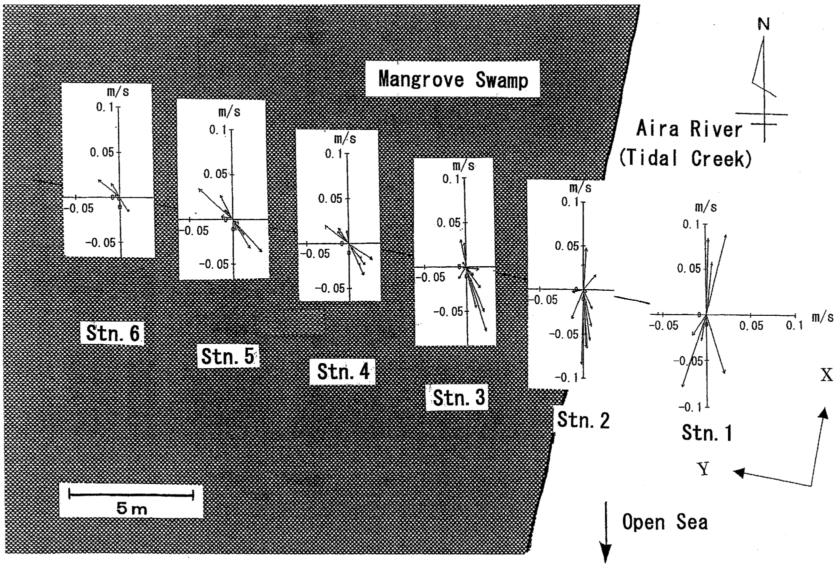

Figure 2. An example of current velocity through a single tidal period on the observation line (2 August, 2000).

transportation and the maintenance of the mangrove ecosystem.

Mechanism of velocity reduction

Consider the mechanism of the velocity reduction in the swamp near the bank of the creek. Figure 3 shows a schematic view of the hydrodynamics in an R-type mangrove area. We set up an x-axis along the creek, oriented up-stream, and a y-axis in the direction normal to the creek. Variables u and v are the velocities in the x- and y-directions, respectively. Mazda et al. (1997b) stated that in the inner part of the swamp, the momentum equation in the y-direction normal to the creek is shown as

$$0 = -g\frac{\partial \xi}{\partial y} - \frac{C_D}{2L_e}v|v| \qquad (1)$$

where ξ is the water level, g is the acceleration of gravity, L_e is the effective length of scale depending on the mangrove vegetation densities and their vertical structures, and C_D is the drag coefficient due to mangrove vegetation. The second term on the right side of Eq. (1) is called the drag force due to the vegetation. Eq. (1) shows that the drag force plays a dominant role in the tidal flow in mangrove swamps.

Considering these findings, the momentum equation in the x-direction, which is parallel to the creek, is shown as follows;

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial \xi}{\partial x} - \frac{C_D}{2L_e}u|u| + f\frac{\partial^2 u}{\partial y^2} \qquad (2)$$

where the third term on the right side is the eddy viscosity and f is the coefficient of the dynamic eddy viscosity.

Generally, considering that the distribution of mangrove trees/prop roots is almost horizontally isotropic, the drag force in the x-direction is probably large in the same manner as in Eq. (1) in the y-direction. When the magnitude of the drag force due to mangrove vegetations is large, it is expected that the shear stress resulting from the vegetation, or the eddy viscosity, also has a significant magnitude. On the other hand, as discussed by Mazda et al. (1997b), a tidal wavelength in creeks is much larger than a spatial scale in mangrove areas. Therefore, the second term on the left side and the first term on the right side in Eq. (2) can be neglected. In addition, a variation of the tidal flow with long periods suggests that the first term on the left side, as mentioned by Mazda et al. (1997b) based on actual measurement, can also be neglected.

If these suppositions are adopted, Eq. (2) is reduced and rearranged as follows;

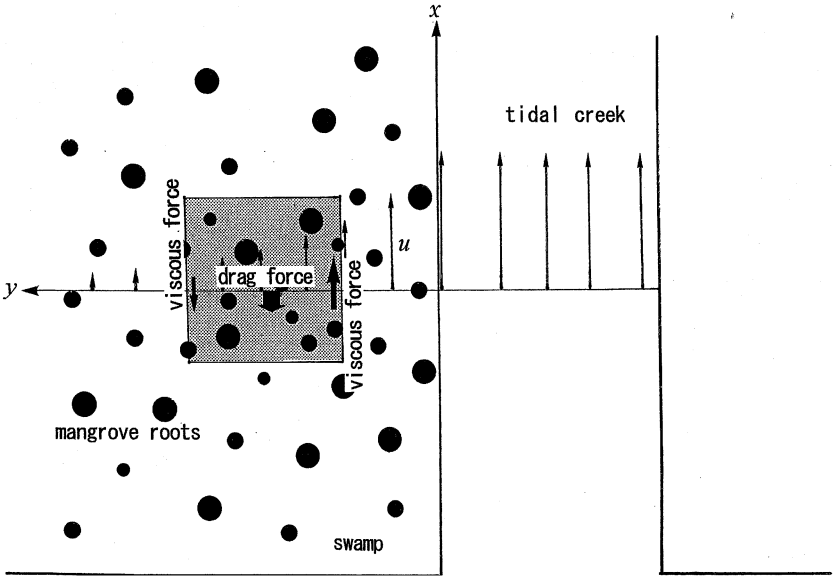

Figure 3. Schematic view of the tidal flow and hydrodynamic forces in the R-type mangroves.

$$\frac{C_D}{2L_e}u|u| = -v\frac{\partial u}{\partial y} + f\frac{\partial^2 u}{\partial y^2} \qquad (3)$$

Eq. (3) shows that the hydrodynamics in the x-direction is formed by the dynamic balance between the drag force and the sum of an advection term resulting from the velocity shear in the y-direction and the eddy viscosity.

Next, we consider the behavior of Eq. (3) in detail. Table 1 shows the signs of each term in Eq. (3) at flood and ebb tides. At flood tide, the signs on both sides of Eq. (3) accord with each other. However, at ebb tide, in order to make the signs on both sides accord with each other, and further to satisfy that the magnitude of the left side, i.e. the drag force, is large, as mentioned above, the magnitude of the second term of the right side must be significantly large compared to the first term. Figure 2, in which v is very small near the bank of the creek, supports this supposition that the first term of the right side can be neglected. Judging from the above, Eq. (3) is approximately transformed as follows;

$$\frac{C_D}{2L_e}u|u| = f\frac{\partial^2 u}{\partial y^2} \qquad (4)$$

Table 1. Sign of each term in Eq. (3).

Eq. (3)	$\frac{C_D}{2L_e}u\lvert u\rvert$	=	$-v\frac{\partial u}{\partial y}$	+	$f\frac{\partial^2 u}{\partial y^2}$
Flood tide	(+)		(+)		(+)
Ebb tide	(−)		(+)		(−)

Eq. (4) shows that the tidal flow in the swamp near the bank of the creek is formed by the dynamic balance between the eddy viscosity resulting from the shear stress due to the tidal flow in the creek and the drag force due to vegetations in the swamp. In other words, in the swamp near the bank of the creek the eddy viscosity is as strong as the drag force. It is well known that the eddy viscosity depends on the current velocity and the spatial scale of the flow field (Ippen 1966). Accordingly, in order to understand quantitatively the flow condition in mangrove swamps, we have to formulate the value of f, which is a coefficient in Eq. (4), using parameters such as the vegetation density of mangroves, their vertical structures and current velocities.

Substituting field data into Eq. (4), the magnitude of f can be determined, because both L_e and C_D have been formulated as functions depending on the tidal magnitude and the vegetation condition (Mazda et al. 1997b). However, before formulating the value of f, we need to confirm the above suppositions, based on the field data. Particularly, in the area near the bank of the creek, the field data within shorter distance than shown in

Figure 2 have to be obtained so that we could discuss with high precision. The authors are collecting such field data, and may present the result in a general paper next time.

Conclusion

Based on the field observation in the Aira-River mangrove area, which is a riverine forest type, the authors obtained the following results. In the swamp near the bank of the creek, the current velocity component parallel to the creek reduces greatly in the direction perpendicular to the creek. The change in the direction of the current velocity in the swamp suggests the existence of horizontal water circulation throughout the swamp. The formations of bottom topography, distribution of water quality, and further mangrove ecosystems in and around mangrove areas are thought to be influenced by these peculiar water movements.

A theoretical discussion shows that the eddy viscosity, which occurs due to the interaction between mangrove trees/prop roots and the shear stress resulting from the tidal flow in the creek, plays an important role in the hydrodynamics in the riverine-type mangroves. In order to develop the hydrodynamics in these areas, we need to formulate the coefficient of the dynamic eddy viscosity, using parameters such as the vegetation density of mangrove trees/prop roots, their vertical structures and current velocities. It was suggested to be able to calculate quantitatively the magnitude of the coefficient, when we could obtain the field data accurately.

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