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Study on environmental change and peculiarity of the Ariake Sea, Japan

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Abstract

The Ariake Sea of Japan is a typical water body surrounded by lowlands, where the area of tidal flats accounts for 40% of all those in Japan and both the tidal flat and the sea have high fishery production. In recent decades, there have been progressive developments such as new harbor, land reclamation and enclosure of a bay. Recent fishery production is abruptly decreasing to a life-and-death problem for fishermen. Many concerned people think that the Ariake Sea is dying through the pollution or change of tidal current caused by such marine works, however an integrated research has not yet been carried out. It is a keen issue to scientifically clarify the characteristics and environmental change of this sea.

In this study, the long-term change of the sea environment is characterized through extensive survey data and information as the first step. Next, the tidal flow and material transport are simulated by the MIKE21 model. As a result, environmental change in seawater temperature, tide level and water qualities are revealed. The simulated results show new fundamental phenomena of tidal current and material transport to be considered for the environmentally sound management of the Ariake Sea.

1 Introduction

The Ariake Sea is one of the unique seas showing various peculiarities. It has the biggest difference of tide level in Japan and very large tidal flats. And then, many endemic species inhabit. About the Ariake Sea, many individual researches in various fields have been carried out till now. However, there is little study example about analysis of present situation and mechanism elucidation of environment from an integrated point of view because oceanographic phenomena is peculiar to the Ariake Sea and the complicated material transport/reaction characteristic exists.

A purpose of this study is to clarify the oceanographic phenomena of the Ariake Sea and to evaluate general water quality phenomena. At first, existing data on water movement and water quality in whole area of the Ariake Sea are collected, and environmental characteristics are examined. Secondary, numerical analysis that used two-dimensional flow/mass transport model (MIKE21) [1] is performed to establish a functional numerical model which can be applied to the Ariake Sea.

2 The Ariake Sea

The Ariake Sea is a typical shallow sea located in west of Japan. Total area of the sea is about 1,700 km^2 with 100 km gulf axial length, 16 km of average width, and 20 m of average water depth (Fig. 1). The basin is very large area extending to 5 prefectures of Saga, Fukuoka, Kumamoto, Nagasaki and Ooita, or 8,400 km^2.

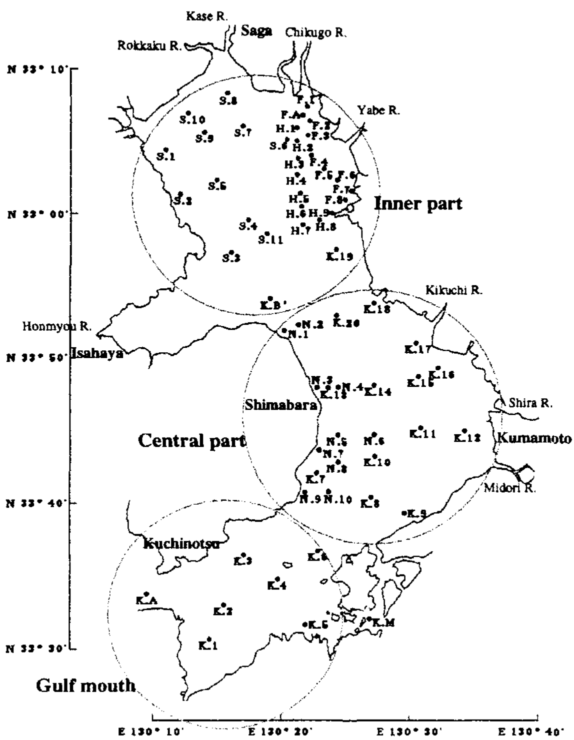

Figure 1: The Ariake Sea and observation points

The Ariake Sea has the largest tidal range in Japan, and it reaches about 6 m at a spring tide in the gulf inner part. A tidal flat appearing with such a large tidal range is also the greatest in Japan. The area of tidal flat is about 207 km^2 or about 40% of a total tidal flat area in Japan. The Ariake Sea is a semi-closed gulf connected to the open sea by only one place at the Hayasaki strait. There are eight biggest rivers flowing into this sea. Endemic species, which were left behind from the Asian Continent, have inhabited in brackish area along the Ariake coast. There is an environmental standard as a goal to preserve water environment in this sea, that is defined for COD, N, P, etc.

3 Environmental characteristics of the Ariake Sea on the basis of observed data

Existing data were collected extensively regarding the sea, the rivers, topography and weather in this area, that is a tide level, tidal current, water quality of the sea, flow discharge and water quality of the inflow rivers and AMeDAS (weather) data. Fixed observation points, total 61 points, in the Ariake Sea are shown in Fig. 1. At these points, regular monitoring and sampling at the high tide of every spring tide have been conducted for 10 to 37 years.

In this study, whole area of the Ariake Sea is roughly divided into three parts according to the difference in salinity to examine the environmental characteristics. These areas are gulf mouth (Hayasaki straight to K.6 point), central part (K.6 point to K.20 point) and inner part (north of K.20 point).

A change in the tide level of each part is shown in Fig. 2. The tidal range is amplified along the gulf axis from the mouth to inner part of the gulf, and phase delays around 25 minutes. Figure 3 shows a tide level change through a year of a monitoring tower located in the inner part. The tide level changes cyclically with about 28-day period unrelated to a season. The level of high and low tide is almost constant from winter to early summer, however low tide level rises about 1m during summer to fall. In other words, the area of tidal flat becomes large during winter to early summer and the largest in low tide of a spring tide in spring season.

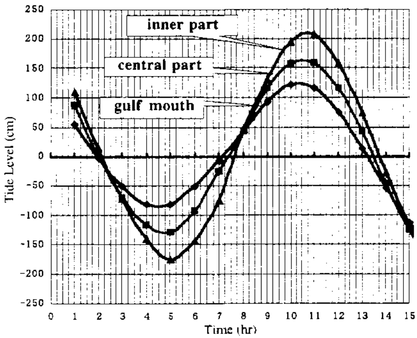

Figure 2: Change in the tide level of each part

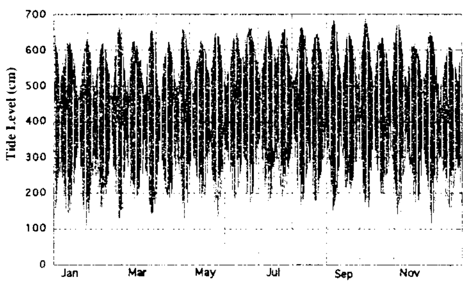

Figure 3: Tide level change through a year at a monitoring tower

Figure 4 shows a change of the mean temperature for the year at each part. The water temperature rises obviously in the whole area of the gulf. So far, a cause is indistinct, but the possibility that an earth scale change (global warming) can be thought about.

Figure 5 shows the transparency at the level of -5m depth in the gulf mouth (K.4), the central part (K.14) and the inner part (S.10) with monthly river flow rate. The transparency is constant and usually low in the inner part due to erosion of the seabed by tidal current, while it becomes higher as approaching the gulf mouth. It tends to be low in the rainy season by the large run off from the rivers. This low transparency in the inner part could have been preventing eutrophication, such as red tide, for a long time in the Ariake Sea.

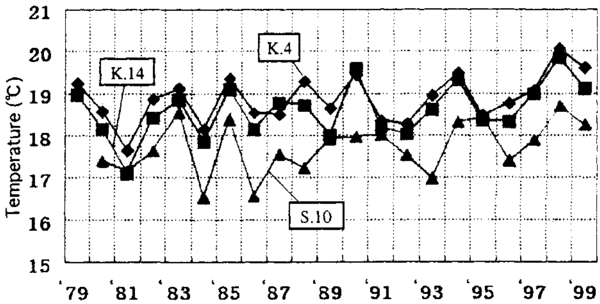

Figure 4: Change of the mean temperature for the year at each part

A change of COD at -5m depth in each part is shown in Fig. 6. On an average, COD is 0.4 mg/l in the gulf mouth, 0.6 mg/l in the central part and 1.8 mg/l in the inner part. A tendency of a slight rise of COD concentration is recognized for this 10 years in all the part. Recently, COD concentration has often exceeded the water quality standard near coastal area. However, in a change of COD load from the rivers, it was rather difficult to detect COD load increasing clearly. Therefore, COD increase is not mainly caused by the inflow load from the rivers but by secondary production and/or release of organic matter from bed mud. It is considered that COD might be almost constant basically in the Ariake Sea because of frequent water exchange with the open sea, and production should be added to it as observed on transparency in the gulf inner part. Detailed examination will be done in future.

As shown in Fig. 7, PO_4-P is also higher in the inner part. There is a distinct seasonal pattern in a change of PO_4-P. It becomes low during winter to early summer, that coincides with the period when the area of tidal flat expands, and high during summer to fall. The same phenomenon was observed on T-N. This is because that uptake and decomposition of nutrients increase under the condition of aerobic and anoxic/anaerobic in the bed mud. Thus, the contribution of the tidal flat to the material cycle is clearly seen in this sea. Detailed evaluation of mass flux on the tidal flat will be done in future.

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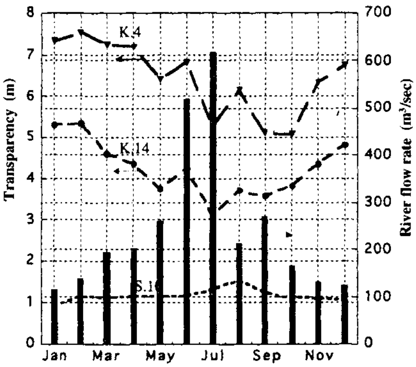

Figure 5: Transparency at the -5m depth

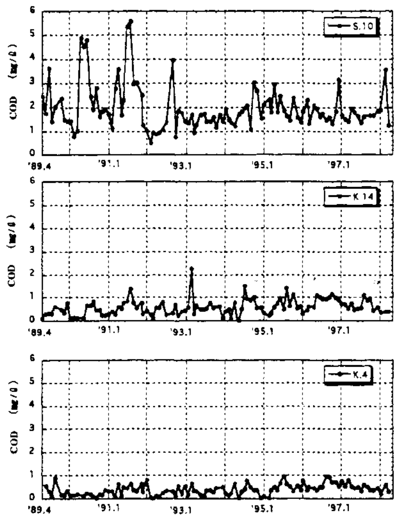

Figure 6: Change of COD at -5m depth

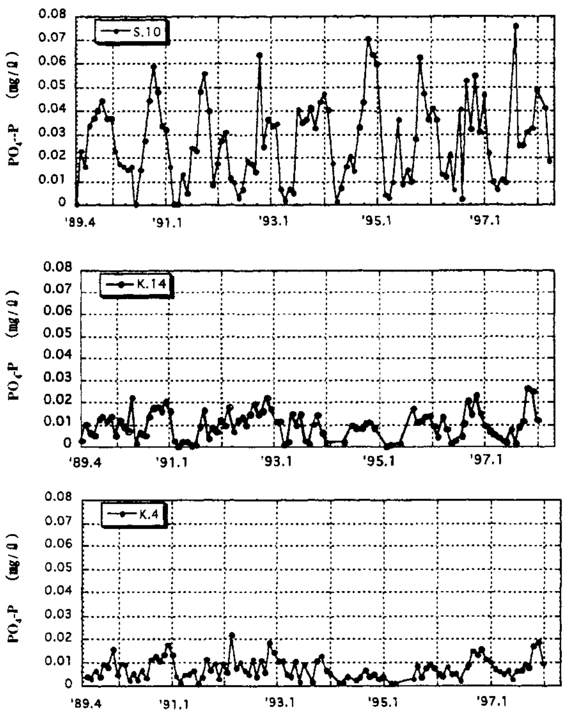

Figure 7: Change of PO_4-P at -5m depth

4 Numerical model and simulation

4.1 Basic equations

The two-dimensional flow/mass transport model was used for numerical simulation. Basic equations of flow and mass transport are shown in the following.

Continuity equation;

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=S-e \tag{1}$$

Momentum equation;
x-direction;

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{g\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\,\frac{p}{h}}{C^2} -fVV_x-\frac{h}{\rho_w}\frac{\partial p_a}{\partial x}-\Omega q-E\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 q}{\partial y^2}\right)=S_{ix} \tag{2}$$

y-direction;

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{g\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\,\frac{q}{h}}{C^2} -fVV_y-\frac{h}{\rho_w}\frac{\partial p_a}{\partial y}+\Omega p-E\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 q}{\partial y^2}\right)=S_{iy} \tag{3}$$

where:
- t: time   h: water depth   ζ: water surface level above datum
- p, q: flux densities in x- and y-direction (p=uh, q=vh)
- u, v: depth averaged velocities in x- and y-direction
- S: source magnitude S_{ix}, S_{iy}: source impulse in x- and y-direction
- e: evaporation rate   g: gravitational acceleration   f: wind friction factor
- c: Chezy resistance number p_a: barometric pressure   ρ: density of water
- V, V_x, V_y: wind speed, wind velocity components
- E: eddy viscosity coefficient   Ω: Coriolis coefficient

Advection-dispersion equation:

$$\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(uhC)+\frac{\partial}{\partial y}(vhC)=\frac{\partial}{\partial x}\left(h\cdot D_x\cdot\frac{\partial C}{\partial x}\right) +\frac{\partial}{\partial y}\left(h\cdot D_y\cdot\frac{\partial C}{\partial y}\right)-F\cdot h\cdot C+S \tag{4}$$

where;

C: concentration of material

D_x, D_y: dispersion coefficient in x- and y-direction

F: decay rate of material

S: Qs(Cs-C)

Qs: source/sink discharge

Cs: concentration of material in the source/sink discharge

An analysis area was divided into 500 m grid, and open boundary was set to the Hayasaki straight. At this point, the observed hourly tide level was given as the boundary condition to calculate water movement, while the actual river discharge was also given at each river mouth. A moving boundary condition was employed to take into account the fact that a shoreline changes far-reaching to more than 5 km in some areas. The observed concentration of target material at each monitoring point is set as an initial condition for calculation of mass transport. Simulation was performed for one year, 1995, by 10 sec. of time step.

4.2 Flow analysis

Shape comparison of the tidal flat on calculation in the gulf inner part and a real tidal flat are shown in Fig. 8. Agreement on both shorelines is good enough for computation. Figure 9 shows comparison of the tide level on calculation and observation. Calculated tidal current is demonstrated in Fig. 10 with comparing to observed data in case of the flood tide. From these figures, it is confirmed that calculated results represent the real tidal phenomena almost completely on tide level, tidal range, phase delay and tidal current.

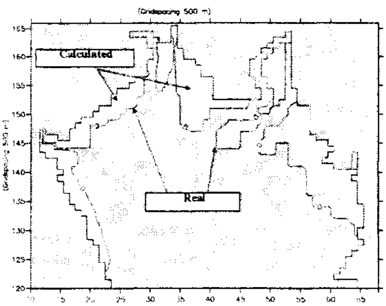

Figure 8: Tidal flat

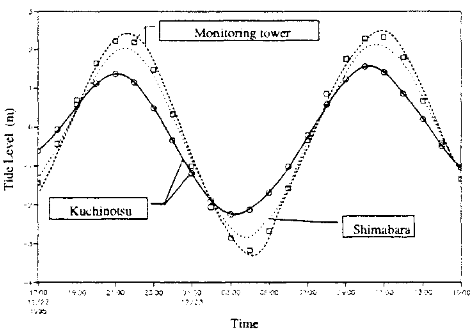

Figure 9: Tide level

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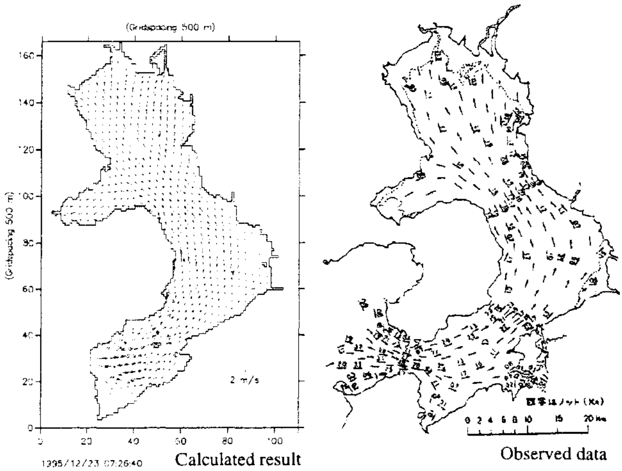

Figure 10: Tidal current

Figure 11 illustrates the calculated tidal residual flow, which also agreed with the observed data. The residual current is rather large at the gulf mouth. At the center and the inner part, the residual current becomes smaller, however, large and small circulating flows are seen at several parts. This complex flow pattern might affect the environment in the Ariake Sea. Low residual current and a lot of circulating flow in the inner part cause high COD through stagnation of organic materials.

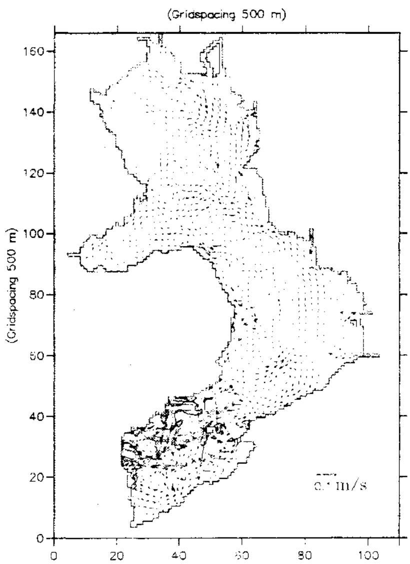

Figure 11: Tidal residual flow

In 1997, the inner part of Isahaya bay where wide tidal flat existed was closed by an enclosure dam in order to construct reclaimed land and a retarding pond for flood control. This project is considered one of main causes of the decrease in fishery production.

Figure 12 demonstrates the tidal residual flow patterns before and after enclosing. Tidal current became slightly small due to enclosure and flow direction was also changed, while tidal range and tide phase became smaller. At the present moment, it is not sure if such slight changes could affect the environment and/or ecosystem and then fishery productivity such as laver. Exhaustion into the serious damage on fishery production, from various viewpoints, has just begun by the government. Establishment of an ecological model, that is improvement of flow/transport model, is necessary work from now.

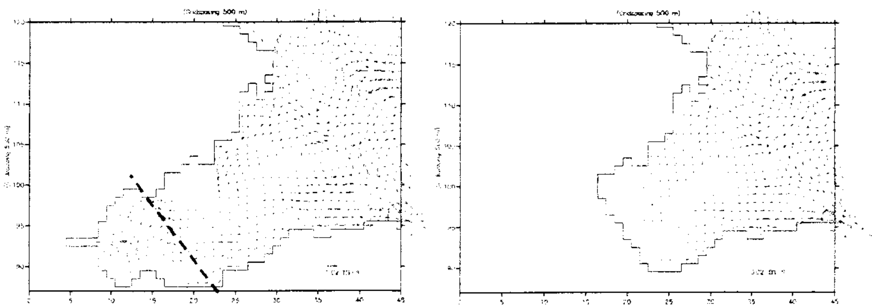

Figure 12: Effect of the closure dam on tidal current

4.3 Mass transport

In this paper, only salinity which is conservative matter is simulated to verify accuracy of the model and parameters such as dispersion coefficient. Salinity contour is shown with the observed data in Figs. 13 (March) and 14 (July). The calculated result represents that salinity is diluted at the inner gulf part by fresh water. From these results, it is seen that this model can reproduce, with good accuracy, spatial distribution of salinity and trace a change with time.

As a result, the employed parameters, such as dispersion coefficient, are adequate for estimation of mass transport as well. Good agreement in transport of conservative matter gives useful knowledge for simulating behavior of non-conservative matter including biological-/chemical-decomposition, production, sedimentation and erosion.

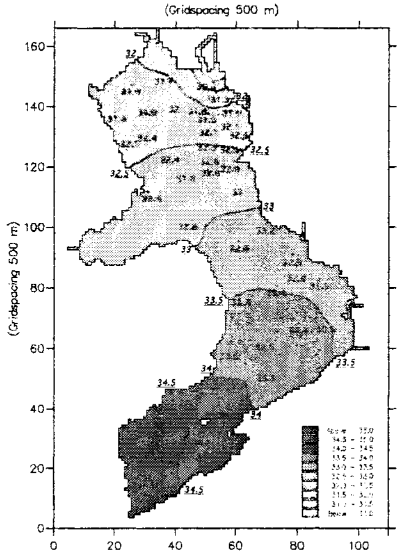

Figure 13: Salinity contour (March)

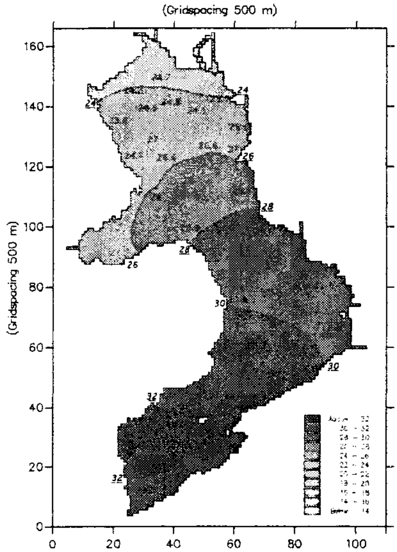

Figure 14: Salinity contour (July)

5 Conclusions

Empirically, the peculiarity of the Ariake Sea has been noticed, however such empirical fact and huge collected data have not been used efficiently for quantitative examination from integrated perspective. In this paper, there is still limitation in examined parameters of water quality and ecological phenomena, however the basic environmental characteristics of this sea were revealed through existed observational data without contradiction.

In the numerical analysis, the functional model with important parameters was established through validation by means of comparison between calculated salinity and observed data. The slight change in tide level and tidal current is recognized through simulating the effect of the enclosure dam. Therefore, it might be considered that the environment and ecosystem of the Ariake Sea is composed of quite delicate balance of physical-, chemical- and biological-phenomena, if abrupt decrease in fishery production is actually affected, via environmental change, by the enclosure dam. This is very significant point for the management of the Ariake Sea and its watershed.

These results will be very helpful for further discussions about water environmental management in this sea as well as a further research especially modelling and numerical simulation.

Reference

[1] DHI. MIKE 21 HD/AD Release 2.7 Users Guide and Reference Manual, 1999.