Numerical Simulation of Sea Water Exchange in Yamaguchi Bay Using FVCOM

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1. Introduction

Yamaguchi Bay is located in Yamaguchi prefecture, Japan. Yamaguchi Bay is semi-closed water with lateral dimension about 8 km x 11 km. The tides and tidal currents are typical of water circulation in Yamaguchi Bay. The type of tides in Yamaguchi Bay is semi-diurnal, in which the M2 is dominant tidal component. Unfortunately we have not found any study concerning to the flow pattern in Yamaguchi Bay yet, either observation experiment or numerical study. It is important to find out the flow characteristics in order to further investigation of water quality and ecosystem in Yamaguchi Bay.

Finite Volume Coastal Ocean Model (FVCOM) developed by Chen et al [2003] is used in our study. FVCOM is based on a Finite Volume Method and three dimensional primitive equations. One unique feature of FVCOM is to use the unstructured grid like a Finite Element Method. The suitability of unstructured grid approach in FVCOM enables us to reproduce coastal ocean currents with high resolution in a complex coastal geometry. FVCOM has been successfully used by several researchers for investigation of the coastal ocean circulation [Chen et al, 2007; Huang et al, 2007], physical mechanism for the offshore detachment [Chen et al, 2008]. Chen et al [2008] examines the particles movement using Lagrangian particle tracking experiment and Bligili et al [2005] uses Lagrangian particle method for study of seawater exchange. In this study we emphasize to establish of seawater flow pattern and also to investigate the seawater exchange in Yamaguchi Bay with the Lagrangian particle method.

2. Model design

The FVCOM used in this research is FVCOM 2.7.1 series. The governing three-dimensional equations are the momentum, continuity, temperature, salinity, and density equations. The turbulence closure model is the modified Mellor-Yamada level 2.5 (*MY-2.5*) for the vertical direction, and the horizontal diffusion coefficients are determined by Smagorinsky eddy parameterization method [Chen et al, 2003].

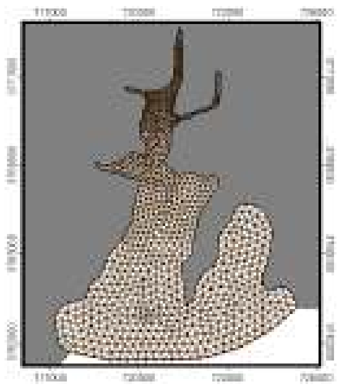


Fig. 1 Unstructured grids

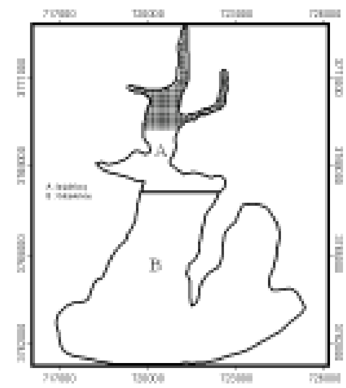


Fig. 2 black circle are initial position of material,
A and B are model region

In this study, FVCOM is forced by (case-1) the M2 tidal level in open boundary (case-2) a constant wind speed uniformly in all elements in model area and (case-3) M2 tide-wind speed incorporated in model calculation. The wind speed was obtained from quick scat satellite data and included in model calculation. In this study we used wind data on May, 2009. The unstructured triangular grid has a horizontal resolution varying from 100 m to 300 m in the open boundary (Fig.1). Since the lack of bathymetric data in Yamaguchi bay, in this study the 5 m uniformly seawater depth was set up. To calculate the vertical flow pattern, the vertical grid was divided into 3 sigma-levels.

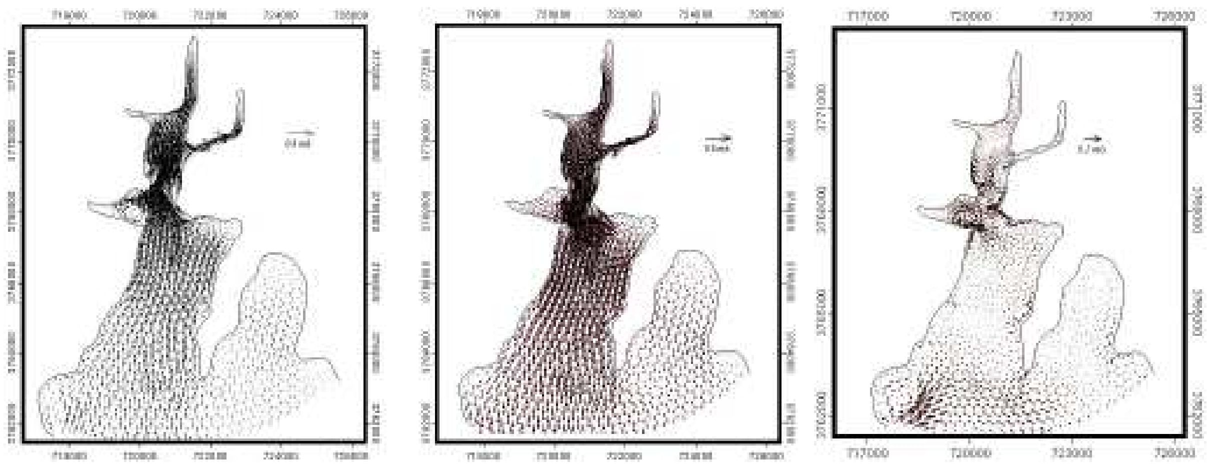
The Investigation of the seawater exchange in Yamaguchi Bay was calculated using Lagrangian particle tracking method. In order to provide the clearly analysis of seawater exchange in Yamaguchi Bay, model area was divided into two regions as shown in Fig. 2.

3. Result and discussion

3.1 Current flow pattern

The calculated tidal current patterns in surface layer of M2 (case-1) are shows in Fig.3 (a) and (b). As a typical of tidal current, the seawater enters to the bay during flood tide and flow out during ebb tide. A strong current occurred in the middle area toward the head of Yamaguchi bay and also occurred in the narrow channel of river. The numerical calculation also show the clearly of clockwise circulation is formed in the middle area of Yamaguchi bay during flood tide, and the speed of this clockwise eddy can reach about 0.1 m/s. From the calculation, the average velocity of M2 tidal current during flood tide is about 0.16 m/s in the surface layer and 0.13 m/s in the local mid-depth (3m below the surface layer). During ebb tide, the average velocity is about 0.15 m/s in the surface layer and 0.12 m/s in the local mid-depth.

The calculated of residual current for case-1 is shown in Fig.3 (c). M2 tidal residual current was formed small clockwise eddy in the middle area of Yamaguchi bay. The somewhat strong residual current was developed in open boundary and middle area of Yamaguchi bay. The average velocity of M2 residual current is about 0.011 m/s in the surface layer and 0.008 m/s in the local mid-depth.



(a) Flood tide (b) Ebb tide (c) residual current

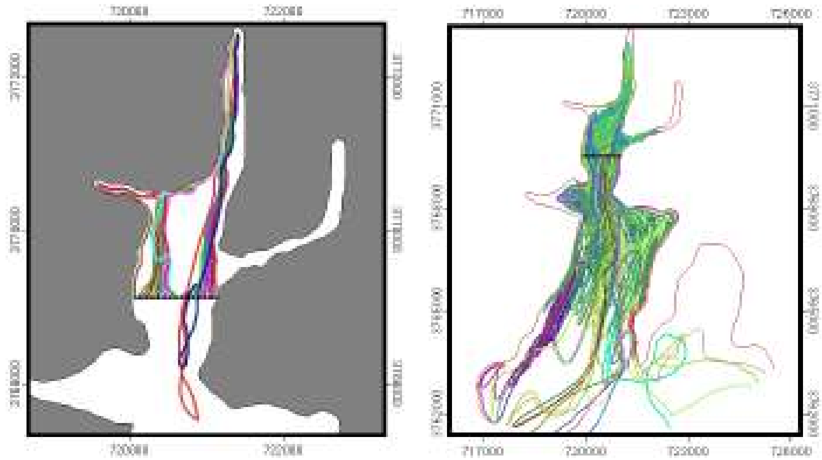
Fig.3 Numerical results for case-1

3.2 Particle transport

In order to examine of particle transport in Yamaguchi Bay, we used Lagrangian particle tracking experiment under the wind-tide current. The neutral buoyant particles were released at surface layer and in the local mid-depth layer. To investigate the particle tracking in Yamaguchi Bay, 22 particles were released inside of bay uniformly along transect and tracked for 30 days simulation. In this case particle released in both two level show significantly different trajectories, an indicator of the inhomogeneous flow field in the vertical. The surface particle distribution is move toward the head of bay (Fig. 4(a)), however some particles are moving offshore in the local mid-depth (Fig. 4(b)).

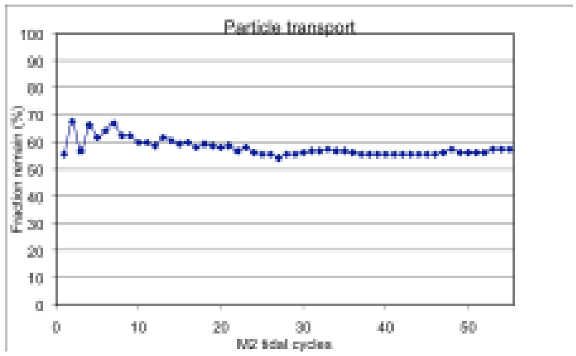
To investigate the seawater exchange in Yamaguchi bay, the Lagrangian particle was tracking under the M2 tidal current (case-1) and wind-tide driven current (case-3). 232 particles were released inside of bay with the initial particle positions is shown in Fig. 3. Fig.5 shows the fractional remain rate in region A for case-1 and case-3.Under the M2 tidal current, the particles were moved to region B about 55% just after particles released. However it seems to be difficult to exported whole of particles from inside of bay, just about 58% particle can move out after 50 tidal cycles.

In the case of the wind-tide driven current, the surface particles has a huge retention to export into region B. It is can be understood due to influence of wind. It is also can be explaining by the wind-tide residual current in surface layer is moving to the head of bay. However the particles exported from region A to region B in the surface layer and in the local mid-depth have a significant different pathway. In the mid-depth layer about 70% of was exported to the region B after 50 tidal cycles. It is also can be explaining by the direction of the wind-tide residual current in the mid-depth layer has an opposite direction with the surface layer.

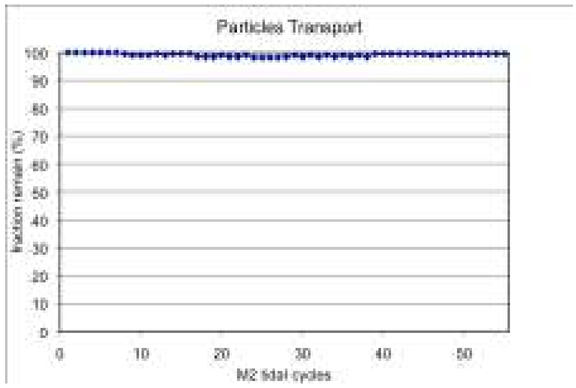


(a) Surface layer (b)3m below the surface

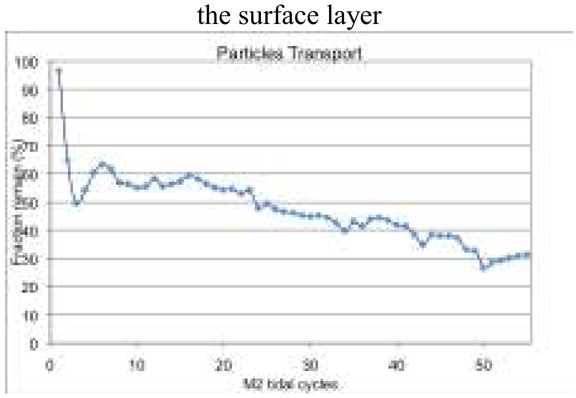
Fig.4 Particle tracking after 30 day simulation(black circle is the initial position of particles)



(a) Transported by tidal current (case-1) in surface layer



(b) Transported by the wind-tide driven current (case-3) in the surface layer



(c) Transported by the wind-tide driven current (case-3) in the mid-depth layer

Fig.5 Fractional remain rate in region A

4. Conclusions

FVCOM was successfully to simulate the flow pattern in Yamaguchi bay. M2 tidal current pattern as a typical current in the semi-closed water was clearly depicted in this study. From the Lagrangian particle tracking, the particle distribution characteristics under the M2 tidal current and wind-tide driven current were clearly depicted. Under the wind-tide driven current, the surface particles were has high retention to flow out into region B, however particle in 3 m under the surface were moving toward the offshore about 70% after 50 tidal cycles.

The water circulation has been calculated using numerical model. However, the model in this paper is not complete enough to make robust conclusions. At present, there are lacks of observation data in order to involving in our calculation. Therefore the result of this calculation is still a preliminary study, which needs the actual input data and observation data to calibrate our numerical results.

5. Refrences

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