Impact of River Discharge on Surface Water Variability in Amagasaki Port, Japan

Ryoichi Yamanaka[1], Yasunori Kozuki[1], Machi Miyoshi[2] and Fumiko Nogami[1]
1 The University of Tokushima
2-1,Minamijyosanjimacho, Tokushima, 7778506, JAPAN
2 Tokushima Bunri University
Shido, Sanuki-city, Kagawa, 769-2193 JAPAN

Abstract-**Amagasaki port is located closed-off section of the Osaka bay, Japan. On the side of the vertical seawalls in the port, a large amount of mussel attached to the objects and drop off to the sea bottom every summer and the mussel drop-off is a pollution load for sea bottom environment. The mussel drop-off is often occurred at the time of sudden water quality change, especially temperature and salinity. Therefore, this study focuses on the period characteristic of surfer salinity in Amagasaki port, wavelet analysis attempt for observed salinity to clarify the occurrence time of the sudden water quality change. Hydrodynamics at the time of river runoff are analyzed by a three-dimensional baroclinic flow model. This study clarified that the occurrence of river runoff was indicated by wavelet analysis at Amagasaki port and the river discharge from Yodo River mainly affected to the sudden change of surface salinity at the sea area, which is a semi-enclosed area and surrounded by reclaimed land.**

I. Introduction

Amagasaki port is located closed-off section of the Osaka bay, Japan, as shown in Figure 1. Almost all coastal areas of Amagasaki port was made by reclaimed land and the coastline have been covered by vertical seawall. On the side of the vertical seawalls, a large amount of mussel (*Mytilus galloprovincialis*) attached to the objects and drop off to the sea bottom every summer and the mussel drop-off is a pollution load for sea bottom environment. According to the latest field observation, the mussel drop-off is often occurred at the time of sudden water quality change, especially temperature and salinity. Threfore, it is necessary to understand the mechanisms of temporal variability of surface temperature and salinity for catching the mussels before the mussel drop-off is occurred. The mussel catching contributes the biomass control at the vertical seawall and which is very important for environment preservation of sea bottom environment. In the north-west part of Osaka Bay, it have been pointed by previous researches(Murota et.al, 1988) that sudden temporal and spatial variation of surfer temperature and salinity are occurred by river discharge. However, there is a complex topography and many sewage plants, it is not clarified the relationship between variation of water quality and river runoff in inlet of the Amagasaki port. Therefore, this study focuses on the period characteristic of surfer salinity in Amagasaki port, wavelet analysis attempt for observed salinity to clarify the occurrence time of the sudden water quality change. Moreover, the hydrodynamics at the time of river runoff are analyzed using a three-dimensional baroclinic flow model..

There are inflows from Yodo river and Mukogawa river and the Amagasaki port is located in estuary region. The water quality of this sea area is seriousness, and the improvement of the water quality is required.

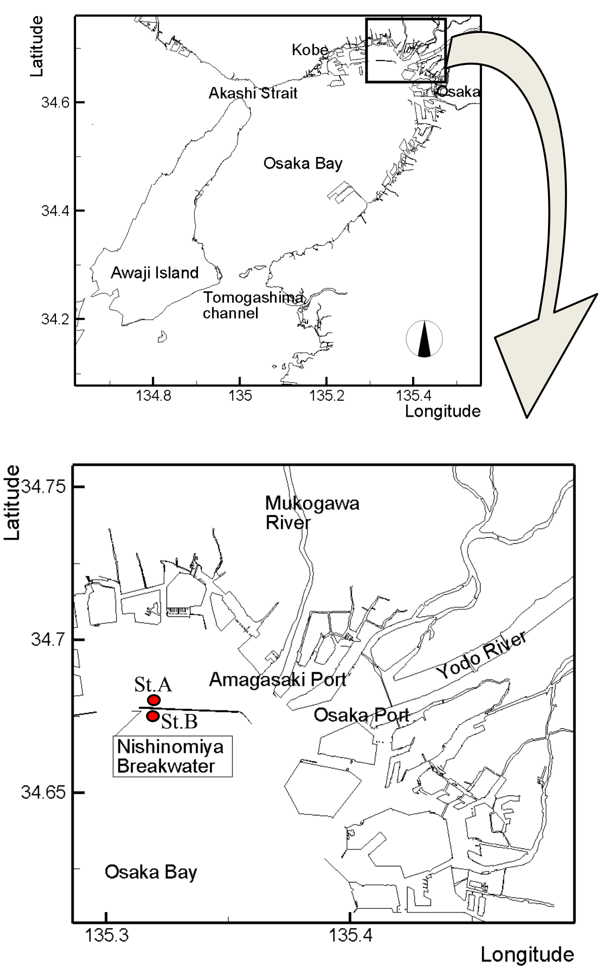


Figure 1. Research area and observation stations

978-1-4244-5222-4/10/$26.00 ©2010 IEEE

II. VARIATION OF SURFER SALINITY

Figure 2 shows salinity variation observed at the depth of 1m at observation station A and B in July 2009. Location of observation stations is shown in Fig.1. According to the observed data, salinity changed drastically in early and late July and fluctuating range of salinity was small in the middle of July. According to comparison the salinity variations in each points, a fluctuation band of salinity at St.B was larger than the result of St.A. Generally, salinity variation is caused by a periodic ocean phenomenon. Therefore, we examine a periodic analysis.

Wavelet analysis is examined for clarity the time series of periodic characteristics of salinity. Wavelet analysis is a temporal-frequency analysis method. Wavelet software was provided by C. Torrence and G. Compo, and is available at URL: http://atoc.colorado.edu/research/wavelets/. Figure 3 shows analysis results for salinity. In these figures, a predominance period corresponding to the large value area, and the predominance period for each time can be identified. According to the results, periodic characteristics of salinity at St.A and St.B are unstable and less than a diurnal period

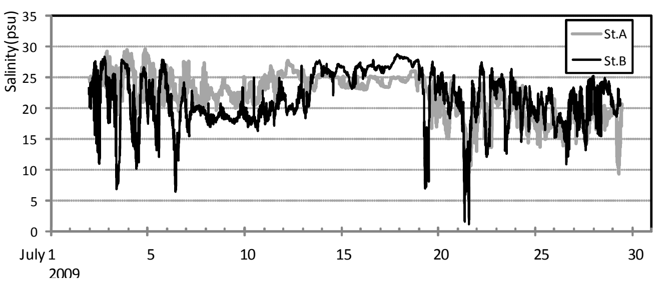
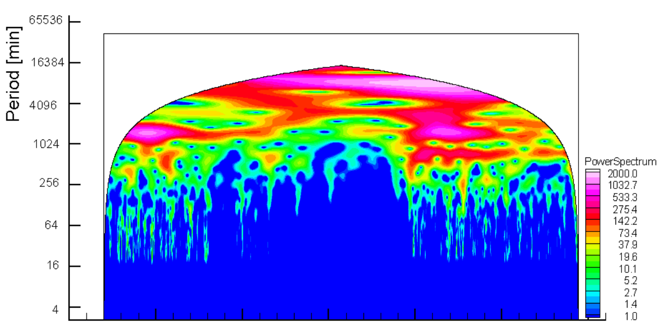
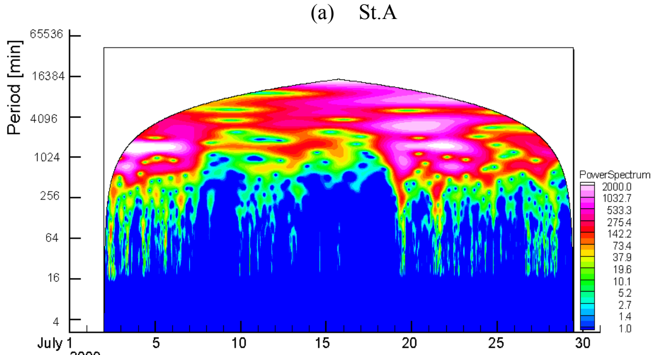


Figure 2.Salinity observed at the depth of 1m at St.A and St.B.



(a) St.A



(b) St.B

Figure 3 Time series of period characteristic of salinity

(=1440min) disappeared in the middle of July. This result is very interesting because the result suggest that flow and density structure changed at this time.

Figure 4 shows meteorological data and discharge rate from Yodo River and Mukogawa River. According to these results, heavy rainfall occurred around July 20 (see Fig.4(a)), and river discharge increased early and late of July. This variability characteristic of river discharge is very similar with time series of salinity at St.A and St.B (see Fig.2). On the other hand, wind condition (see Fig.4(d) and (e)) is unstable and wind speed and direction changed for short instance. It seems that there is less relationship between wind speed variation and salinity variation. Consequently, it is found that river discharge is a dominant factor for variation of surfer salinity around Nishinomiya Breakwater. However, the reason why the difference of fluctuation band of salinity was induced between St.A and St.B and generation mechanism of the variation of salinity has not clatified yet.

III. NUMERICAL MODEL

A. Baroclinic Flow Model

This study applied a quasi-3D baroclinic flow model, ODEM (Osaka Daigaku Estuary Model), which was originally developed by Nakatsuji in 1987 (Murota et al., 1988).

The basic hydrodynamic equations are based on the three-dimensional conservation law for mass, momentum and scalar quantities, namely, temperature and salinity under the Boussinesq approximation and hydrostatic assumption. Density is calculated as a function of temperature and salinity. The mathematical model is formulated by integrating the basic equations with respect to each control volume and by transforming them into finite-difference forms on a spatially-staggered grid system in horizontal and vertical planes. Since the vertical momentum equation consists of only the gravity and vertical pressure gradient terms owing to the hydrostatic approximation, the vertical velocity component must be computed so that the continuity equation is satisfied for each control volume. The free surface elevation may be computed by applying the continuity equation to a vertical column of water from the sea bottom to the water surface. An explicit leapfrog method was used in time; however, a semi-implicit scheme was used for the computation of water level in order to prevent numerical instability. The eddy viscosity and diffusivity were used to represent the turbulent transport of constituents. Since the vertical transport is reduced by stratification caused by the density difference, the vertical eddy viscosity and diffusion coefficients must be a function of the Richardson number. Following the study of 3-D buoyant surface discharges by Murota et al. (1988), the present computation adopted Webb's formula (1970) for eddy viscosity and the Munk and Anderson formula (1948) for eddy diffusivity, respectively. Both empirical formulas are functions of the gradient Richardson number. Their values in un-stratified conditions are set to be $Av0=0.001m^2/s$. In addition, the Henderson- Sellers' formula (1985) was applied to consider the wind-induced vertical mixing. On the other hand, the horizontal viscosity and diffusion coefficients were determined by the sub grid scale (SGS) concept proposed by Smagorinsky (1963). These coefficients were determined based on a comparison with field surveys and hydraulic model experiments (See Murota et al., 1988).

B. Numerical Arrangement

Grid system

The computational domain is shown in Figure 5. The horizontal grid sizes varied between 1km and 3km on the rectangular grid with vertical grid size are set from top to bottom as: 2.0m, 1.0m,1.0m, 1.0m, 1.0m, 1.0m, 1.0m, 1.0m, 1.0m, 1.0m, 1.0m, 2.0m, 2.0m, 2.0m, 2.0m, 3.0m, 5.0m, 7.0m, 10.0m and 15.0m. The model uses an Arakawa-C grid in the horizontal and z-system in the vertical direction. The bathymetric data was obtained from the marine chart. The time step is 5 seconds.

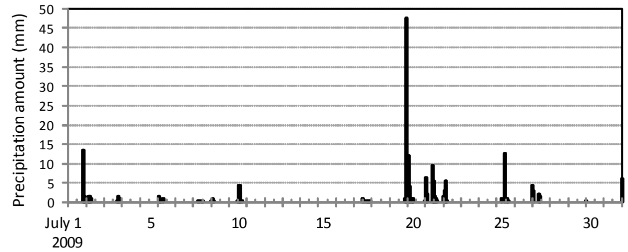
Boundary and Initial Conditions

Sea surface height and velocity: The sea surface elevation at the open boundary is determined from two coastal tidal gauges, Murotsu in the north and Wakayama in the south. Seven major tidal constituents Sa, O_1, P_1, K_1, M_2, S_2, K_2 were considered. The values of the harmonic constants were obtained from Japan Coast Guard and Japan Meteorological Agency. The flow structure at the open boundary was determined by a zero-gradient condition.

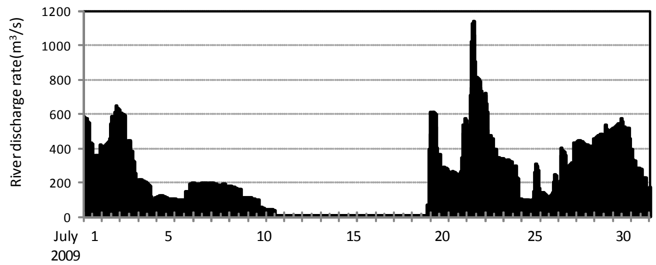
Salinity and Temperature: The initial salinity and temperature distributions were set to constant value as T=9.0(^{o}C) and S=32.0 (psu). The values of temperature and salinity at the open boundary were determined by monthly averaged distribution obtained from related organization and a zero-gradient condition was applied when the water flows out from the model domain.

Meteorological effect: The wind speed and other meteorological parameters (air temperature, shortwave radiation and cloud cover) were found by observation data of Osaka obtained from Japan Meteorological Agency. The heat balance at the air-sea interface is calculated according to Murakami et al. (1989). The heat balance is composed of four constituents: short-wave radiation, long-wave radiation, sensible heat, and latent heat of evaporation.

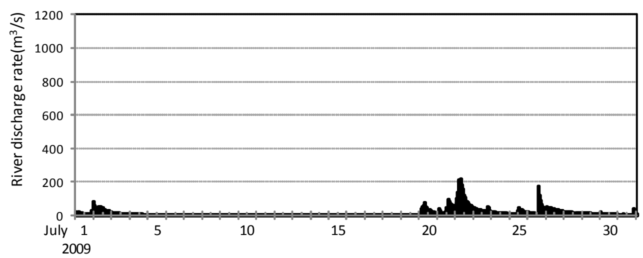
River runoff: The river discharge from two rivers was considered. The locations of river mouths are shown in Fig.1. The discharge rates are determined by a hourly rate which is shown in Fig.4



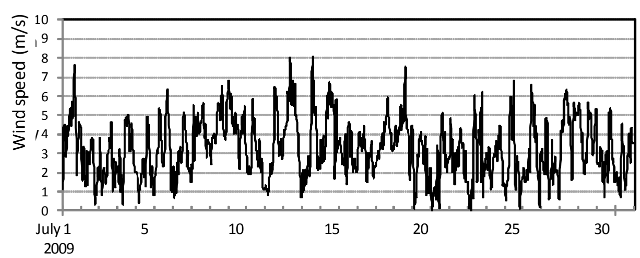
(a) Amount of rainfall



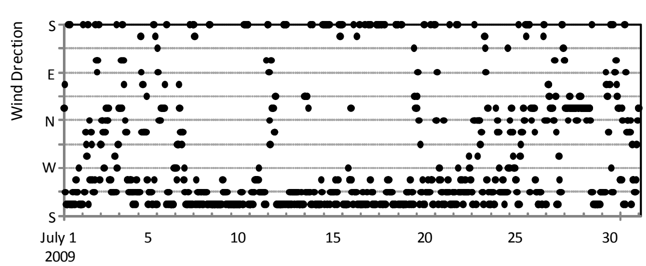
(b) Discharge rate of Yodo River



(c) Discharge rate of Mukogawa River



(d) Wind Speed at Osaka



(e) Wind Direction at Osaka

Figure 4. Meteorological condition and river discharge rate in july 2009

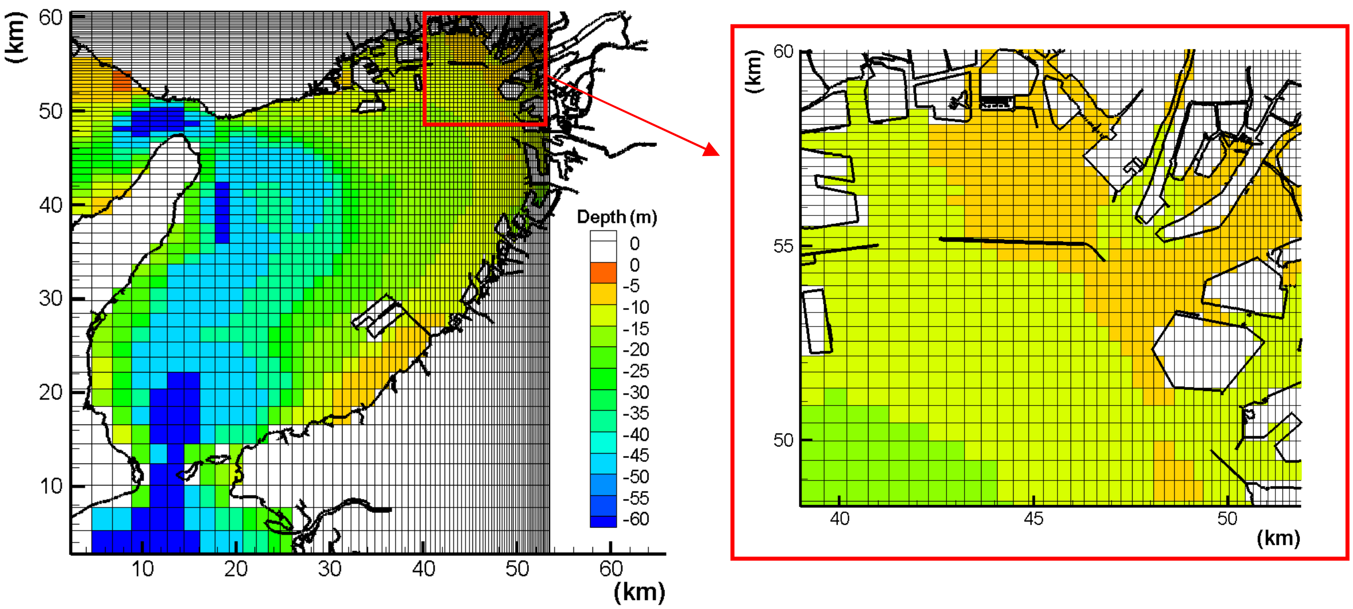


Figure 5.Computational domain, grid system
and distribution of water depth

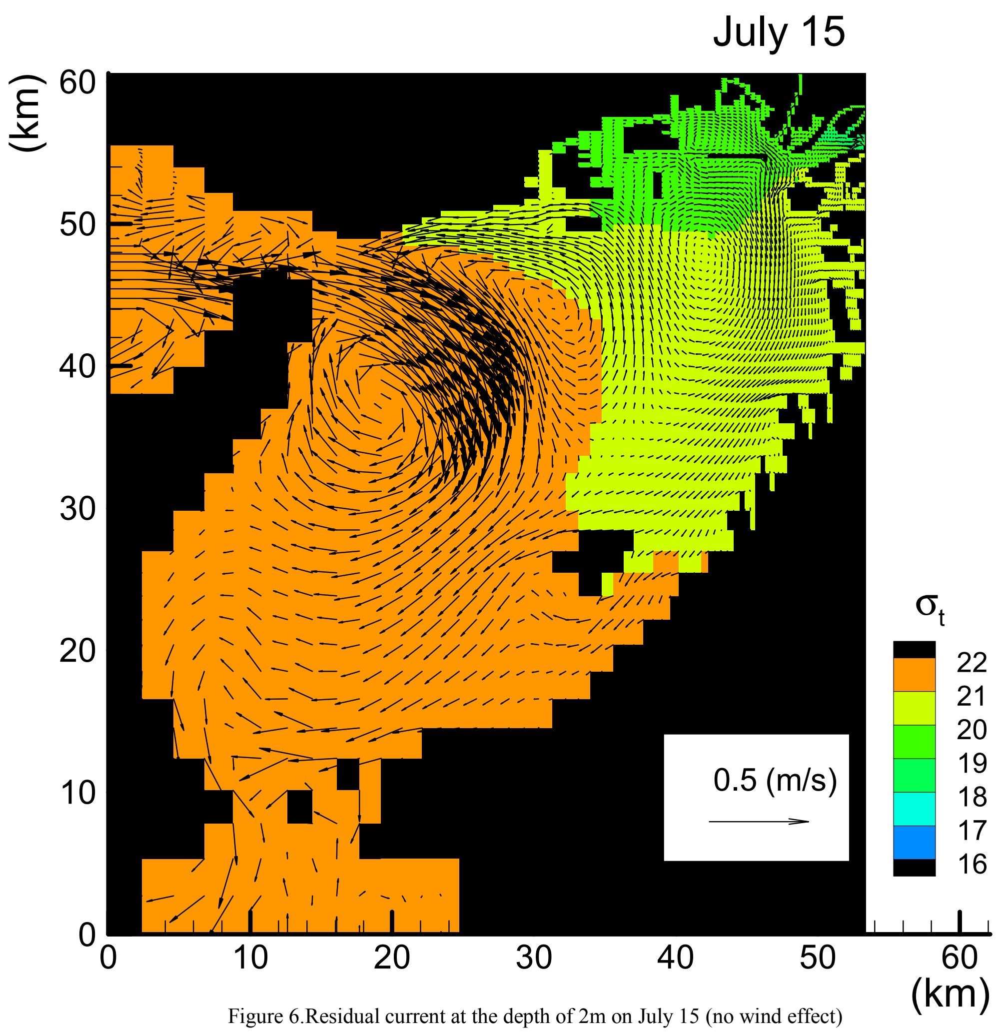


Figure 6.Residual current at the depth of 2m on July 15 (no wind effect)

Computational Approach

A period from January to July in 2009 was simulated. The hindcast simulation used the baroclinic flow model to simulate the flow and density structure with meteorological forcing and river runoff. The dispersion and deposition process of the river water, without Nishinomiya Breakwater, on July were also simulated to evaluate each effects on river water distributions.

IV. RESULT AND DISCUSSION

A. Verification

Figure 6 shows a distribution of tidal residual current and density at the depth of 2m in July 15. This result is not take account of wind effect. The feature of residual current system has already clarified by Nakatsuji and Fujiwara (1997). There is a geographical vortex in western area of Osaka Bay called "Okinose-Kanryu" and Anti-cyclonic circulation in eastern area of Osaka Bay.

According to the comparison between Fig.6 and previous research results, this computed result represents the features of residual current system well.

B. Variation of surfer salinity.

Figure 7 shows a computed time series of salinity at the depth of 1m at St.A and St.B. According to the comparison between Fig.2 and Fig.7, numerical result does not represent the sudden lowering of salinity which occurred in early and late July. However the decreasing for several days is simulated qualitatively. Figure 8 shows the time series of period characteristic of computed salinity, obtained by wavelet analysis. The disappearance of less than diurnal period in middle July are simulated well. It follows from this that the periodicity on salinity variation appears only when freshwater inflow from rivers. Moreover, this periodicity is more pronounced in the southern breakwater.

On the other hand, period of less than about semi-diurnal do not appear in numerical result. It is likely that this problem caused by lack of space resolution in vertical direction and wave effect.

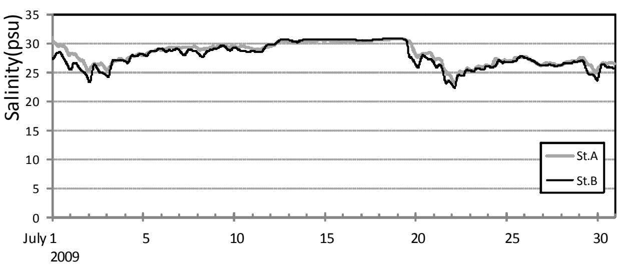
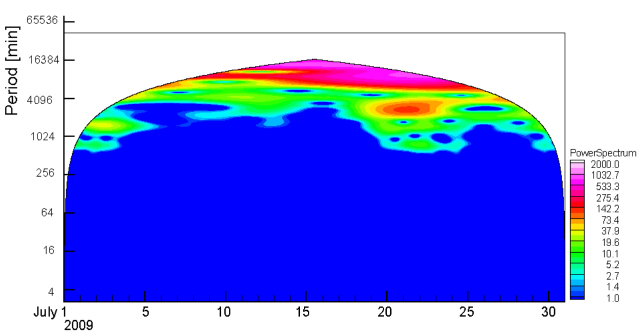
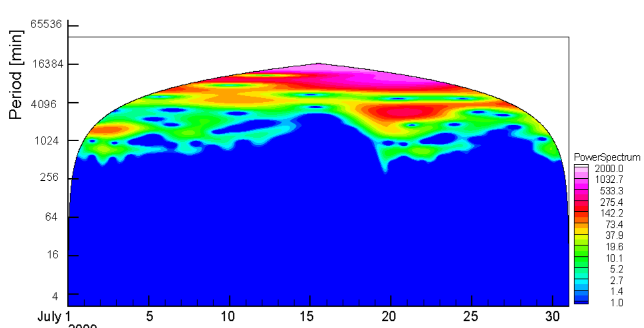


Figure 7. Computed salinity at the depth of 1m at St.A and St.B.



(a) St.A



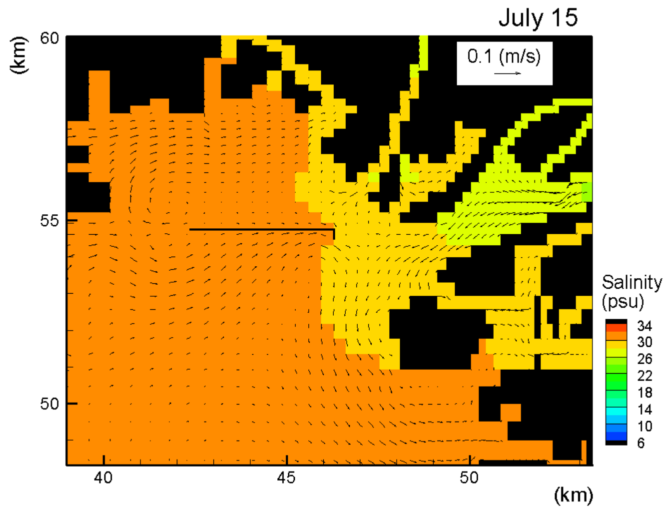
(b) St.B

Figure 8. Time series of period characteristic of salinity

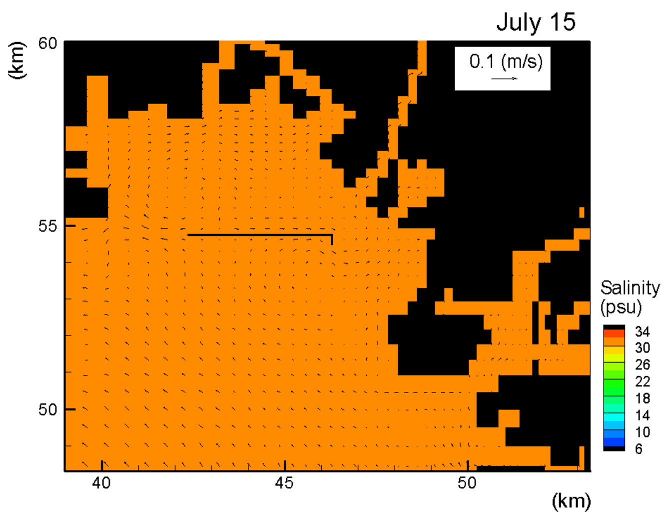
C. Variation of flow structure caused by river runoff

Figure 9 and 10 show a computed result of distribution of residual flow and salinity at the depth of 2m and 7m on April 15 and 21. According to a comparison between surface flow structure, as shown in Fig.9 and Fig.10, residual current of surface is changed drastically in 6 days and flow structure of April 21 denote typical flow structure of estuary. After river runoff occurred, low sanity water spread from river mouth and distribution of salinity is discontinuous in north-south direction across the Nishinomiya breakwater.

Vertical density distribution is shown in Figure 11. There is vertical density stratification on April 15 and 21, however, the strength of stratification is not same. The result after river-runoff, as shown in Fig.11(b), shows that strong density stratification is generated along the south-north line and the strength of stratification in southern area of the breakwater is stronger than one in northern area of the break water. This stratification was induced by the river discharge and river water of Yodo river seems to flow to southern are of the breakwater in Fig.10(a). Therefore, the shape of stratification is not same and stratification formed at the depth of about 3m in southern area of the breakwater, however there is weak stratification in northern part of breakwater. Because of the stratification in southern sea area, salinity is easy to fluctuate by moving of the density stratification. Consequently, periodicity of variation of salinity is induced by vertical moving of the density stratification and diurnal and semi-diurnal period is appeared because the variation of salinity generated by tide and this is a reason why the difference of fluctuation band of salinity was induced between St.A and St.B. Because of mussel attached in this sea area at the depth of 1 or 2 m, the impact might affect mussel directly, especially in southern area of the breakwater.

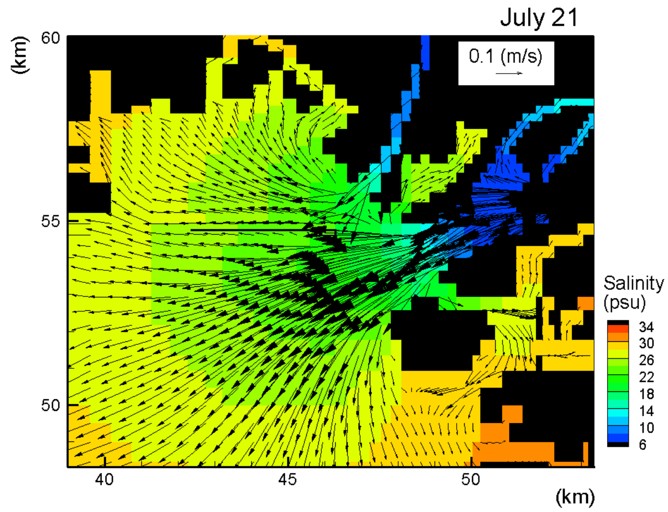


(a) On surface

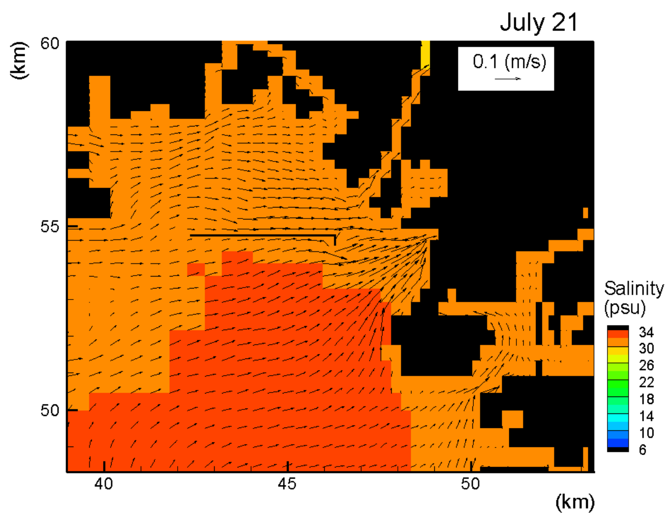


(b) at the depth of 7m

Figure 9.Distribution of residual flow and salinity on July 15

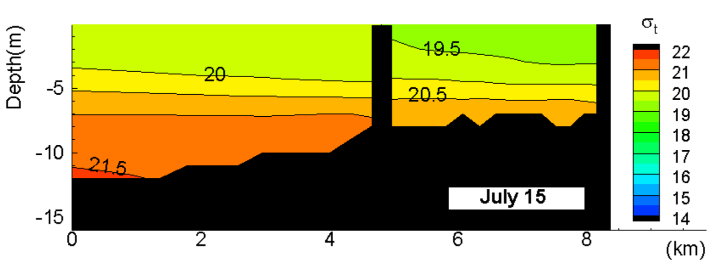


(a) On surface

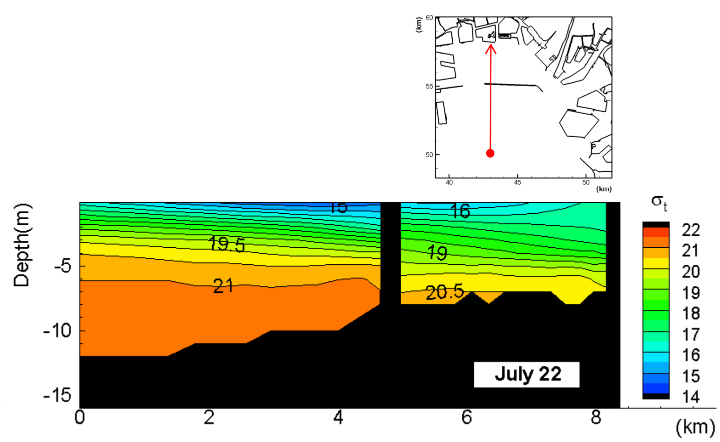


(b) at the depth of 7m

Figure 10. Distribution of residual flow and salinity on July 21



(a) July 15



(b) July 21

Figure 11. Distribution of vertical density profile along a south-north transect by numerical simulation

V. CONCLUSION

Main results obtained in the present study are summarized as follows:

(1) The temporal period characteristic of surfer salinity are clarified by wavelet analysis. According to the result of wavelet analysis, it is mainly dominated by diurnal and semi-diurnal periodicity and randomly the periodicity are lost for a few days. The results of comparison of river runoff and temporal period characteristic of water quality, the periodicity were disappeared at the time of occurrence of high river discharge by Yodo River.

(2) The result of numerical simulation shows that the river water of Yodo River spread through narrow waterway which surrounded by artificial lands and breakwaters located near the coastal lines. The impacts of river runoff of Yodo River reached to the Amagasaki port, although which is semi-enclosed see area and located right side of the river mouth of Yodo River. The results of numerical simulation also show vertical distribution of salinity. According to the numerical results, the phenomenon is mainly indicated above the density stratification which was formed at the depth of 2m. Because of mussel attached in this sea area at the depth of 1 or 2 m, the impact might affect mussel directly.

This study will contribute the biomass control at the vertical seawall and which is very important for environment preservation of sea bottom environment.

REFERENCES

[1] Henderson-Sellers.B. (1985). “New formulation of eddy diffusion thermocline models” Appl. Math. Modeling, Vol. 9, pp.441-446.

[2] Munk, W. H., and Anderson E. R. (1948). “Notes on a theory of the thermocline” J. Marine Research, Vol. 7, pp.276-295.

[3] Murakami, M., Y. Oonishi and K. Hayakawa (1989). ”Heat and Salt Balances in the Seto Inland Sea” Journal of the Oceanographical Society of Japan, Vol. 45, pp.204-216.

[4] Murota, A., K. Nakatsuji and Huh J. Y. (1988). “A numerical study of three- dimensional buoyant surface jet” Proceeding of 6th APD-IAHR Congress, Vol. 3, pp.57-64.

[5] Nakatsuji, K. and Fujiwara T. (1997). “Residual baroclinic circulations in semi- enclosed coastal seas” J. Hydraulic Engineering, ASCE,Vol.123, No.4, pp.362-373.

[6] Smagorinsky, J. (1963). “General ic researches 1980, No.15, pp.55-70. circulation experiments with primitive equations, Monthly Weather Review” Vol. 91, No.3, pp.99-164.

[7] Webb, W. K.(1970). “Profile relationships, the log-linear range and extension to strong stability” Quarterly J. Royal Meteorological Soc., 6, pp.67-90.