［別紙１］

論文の内容の要旨

論文題目 Numerical Simulation of Residual Currents and Water Quality in Semi-Enclosed Bays
（半閉鎖性内湾における残差流と水質の数値計算）

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The overall objective of this study was to analyze the seasonal change of residual currents (RC) in semi-enclosed bays and to investigate its impact on water quality. Comprehensive investigation was performed on the spatial as well as temporal variation of residual currents considering its interaction with prevailing wind stress, bay geometry and fresh water inflow through numerical simulations and field observations. Tokyo Bay was primarily selected as the study area and observation data at Ariake Bay was later included for the analysis of temporal variation of residual currents.

Although there have been several studies on the spatial distribution of residual currents in semi-enclosed bays including Tokyo Bay, in the present study a very simple approach was adopted to clarify the phenomena. Numerical evaluations were performed in simple ideally shaped domains to examine the circulations created by different forcing factors under stratified and well-mixed conditions, and later they were combined to analyze the variation of spatial distribution of residual current in Tokyo Bay during different seasons.

Numerical experiments showed, during the well-mixed conditions of winter, the circulation is dominated by the bathymetry of the bay and wind direction. As Tokyo Bay is deeper along the western coast the north wind creates a stronger current along the eastern coast and at the same time there is diverging current along the east coast due to the Coriolis effect. This results in anti-cyclonic circulation in the bay. Analysis of the pressure distribution revealed that the main force balance during this period is between the Coriolis force and the static pressure, with the dynamic pressure only shifting the circulation center between the upper and lower layers.

During the stratified conditions of summer, with surface heating as well as increase of fresh water inflow, wind driven current (Ekman current) is only limited within the upper few meters. During this period, contribution from dynamic pressure becomes significant. Under stratified conditions, circulations below the interface are under indirect influence of wind. The change in surface elevation due to wind stress and the density gradients creates horizontal pressure gradients which is balanced by the coriolis force, in other words geostrophic balance controls the circulations in the lower parts in Tokyo Bay during the stratified conditions of summer.

The zero-equation mixing length model (MLM), based on Prandtl’s theory and Richardson number was found to be efficient in simulating the stratified density structure during summer but it was not flawless when residual current was simulated at moored measurement stations, especially for bottom velocity. This obligated the necessity to incorporate a higher order turbulence closure scheme into the present model so that a better representation of mixing coefficients are obtained at least in

terms of theoretical point of view. In the newly incorporated turbulence model (Mellor-Yamada model or MY model), condition to restrict the mixing length was included to ensure satisfactory simulation of stratified density structure. Simulated results of temperature and salinity showed reasonably good agreement with observed data at different observation stations in Tokyo Bay, indicating the model's capability to represent stratified conditions acceptably well.
Results for residual currents simulated with the MY model showed better agreement with the observed data compared to MLM, especially at bottom layers. The basis appeared to be over estimation of stratification by MLM. The RC simulated with MLM was significantly small in amplitude compared to MY model which could be due to the small mixing allowed by MLM and this was overcome by MY model. In other words, MY model seemed to give a better representation of mixing coefficients, compared to MLM when the RC data at measurement stations were compared.

The temporal change of residual currents at moored measurement stations enabled to study the vertical structure of the velocity field with the change of the meteorological as well as hydrological (river discharge) forcing factors. Observation of vertical distribution of residual currents showed the formation of single layered or multilayered vertical circulations during summer and winter respectively, which was expected due to the seasonal change in density structure in Tokyo Bay and they were well represented by the numerical simulation.

An interesting phenomenon, observed during this present study was the 'Intensification of Middle Layer Return Flow' (IMLRF) due to north wind at Tokyo Light Beacon. Such kind of strong return flow was not associated with south wind at the same station. Numerical simulation succeeded in simulating such IMLRF phenomena. Simplified ideal case experiments were performed under stratified conditions with steady north and south wind considering the bathymetric effects. From these experiments, it appeared that the set-up and set-down of the interface in association with the slandering and thickening of the Ekman layer depth, under the influence of north and south wind, respectively, could be the core factors behind the mechanism of IMLRF. Also, such experiments suggested that IMLRF is prominent in the western coast. Observation data at CLB were investigated and it did not exhibit such IMLRF phenomena under the influence of north wind supporting the ideal case experimental result interpretation. The inexistence of IMLRF phenomena at the east coast was explained from the pressure distribution point of view where the additional static pressure created by the surface elevation at the western coast plays key role in producing the IMLRF, which is absent at the east coast. So, in the Northern hemisphere, such kind of IMLRF phenomena is expected to appear along the western coasts in bays having a slope in its head (north) region due to north wind under stratified conditions and in the Southern hemisphere it is expected to be vise-versa.

A specific duration, during 2004, was selected to study the effect of residual current on water quality in terms of blue tide occurrence. Numerical simulations, to calculate the residual currents, density structure as well as dissolved oxygen, were performed to investigate the hydrodynamic as well as water quality status on those specific days when blue tides occurred. As blue tides are associated with the upwelling of anoxic water to the surface, meteorological phenomena like wind speed and direction, and bathymetry of the bay play significant role. By analyzing the periods when blue tide did not occur despite similar meteorological conditions, two other factors; movement

of anoxic water in the bottom layers of the bay and strength of stratification were found to be very important. A coupled modeling approach, consisting of a meteorological model and a hydrodynamic-water quality model, could become useful for future studies on blue tide prediction.