Calculation conditions

We conducted a simulation covering 123 days from 1 July to 31 October 1989, based on the input data described above. We checked the responses of the model to the given data by comparing the calculated results with observed temperature, salinity and velocity at several points in Tokyo Bay.

3.3 Simulation Results

The performance of our model was compared with the following observations of temperature, salinity and velocity in Tokyo Bay. The Hydrographic Department of Japan conducted sequential monitoring of temperature, salinity and horizontal velocity (north-south and east-west components) at 4 mooring stations from 11 September to 21 October 1989. A water quality survey for public water is made by the Tokyo, Chiba and Kanagawa Prefectures approximately once a month. Using data from mooring stations, the tidal ellipses and energy spectra were analyzed. Tidal ellipses and energy spectra derived from model calculation results are compared in the following section. Calculated results of temperature and salinity were compared with observed values at station A where the sequential monitoring by the Hydrographic Department of Japan was conducted. The water quality survey data were used to check the model in terms of spatial distribution of temperature and salinity.

Tidal ellipses

Tidal ellipses for Station A and D (Fig. 3.2) drawn using measured and calculated velocity are compared in Fig. 3.7. The constituents O_1, K_1, M_2 and S_2 of the observed data for depths of 1.5 or 3.0 m and 10 m were compared with those of simulated data for the same depths. The calculated results agreed quite well with the observations. Our model simulated accurately the characteristics of the water flow driven by tidal currents.

Comparison of energy spectra

The purpose of comparing energy spectra is to check flow fluctuation caused by factors other than tidal currents. Energy spectra of the observed and calculated horizontal velocity were compared at stations A and D (Figs. 3.8, 3.9). Flow driven by tidal currents was shown to be simulated well by comparison with tidal ellipses. Diurnal and semi-diurnal fluctuations agreed well and were consistent with the similar agreement in tidal ellipses. However, energy at higher frequencies was underestimated by our model. Although the use of the method by Smagorinski (1963) improved energy spectrum calculations at high frequencies, the grid size adopted in the present application is too coarse to simulate the small vortices that exist in Tokyo Bay. Smaller grids would improve the discrepancies at higher frequencies. However, we did not adopt a smaller grid size due to the restraint of calculation time.

Temperature and salinity

Observed and simulated data for Station A for 11 September to 21 October 1989 are shown in Figs. 3.10 and 3.11. The simulation results agreed quite well at the surface. The timing of reversal of temperature stratification and intermittent increase of bottom water temperature was also simulated well. Since the simulation results underestimated high-frequency variations as shown in Figs. 3.5 and 3.6, sudden fluctuations were not simulated as intensively as actually observed. However, the simulation results showed satisfying agreement in the patterns of temperature and salinity variation at the surface, which is important in analyzing Awoshiwo occurrences. These patterns in temperature and salinity variation during Awoshiwo events are discussed in next section.

Calculated and measured vertical profiles of temperature and salinity at several stations are compared in Fig. 3.12. Observations on 25 September 1989 showed that surface salinity at stations 3, 4, 5, 6, and 11 was low due to freshwater discharge from rivers. Our model simulated this vertical salinity stratification pattern with good agreement except at stations 5 and 11, which were close to the mouth of the Sumida River. These discrepancies were attributable to errors in estimation of the freshwater discharge from the Sumida River. Comparison of vertical temperature and salinity profiles at several points showed that the balances of energy and salinity were successfully reproduced by our calculations. In particular, vertical profiles of temperature and salinity in the northern part of the Bay, where Awoshiwo events are observed and which was the focus of our study, are simulated in excellent agreement.

Results of simulation of Awoshiwo events

To analyze the mechanism leading to the outbreak of Awoshiwo events, we examined the observed temperature and salinity fluctuations and compared them with the simulation results.

Two Awoshiwo events, beginning on 23 September and 2 October 1989, respectively, were considered here; data from sequential measurements of current, temperature and salinity were available for these two events and water quality sampling was conducted on 27 September and 3 October. The first Awoshiwo event, on 23 to 24 September, was small scale (~ several km), while the second, on 2 to 4 October, was intermediate in scale (~ 10km).

A northerly wind of velocity more than 5 $m.s^{-1}$ blew continuously on 24 September and 2 October 1989 when the Awoshiwo events were observed (Fig. 3.6). The northerly wind seems to have led to their occurrence. During the Awoshiwo events, the observed surface temperature at St. A showed a rapid decrease (i.e. by 2℃ from 23 to 24 September and by 3℃ from 2 to 4 October); surface salinity increased dramatically (i.e. by 7‰ from 23 to 24 September and by 5‰ from 2 to 4 October) (Figs. 3.10(a), 3.11(a)). The water quality changes common to the two Awoshiwo events were dramatic change at the surface (i.e. temperature decrease and salinity increase) and little change at the bottom (Figs. 3.10 (a), 3.11(a)).

The calculated results showed similar trends in temperature and salinity in the grid closest to St. A. (Figs. 3.10 (b), 3.11(b)). Calculated surface temperature dropped by 1℃ and 2℃, respectively, during the two event periods; calculated surface salinity increased rapidly by 8‰ and 4‰, respectively, while calculated bottom temperatures and salinities did not show conspicuous change.

Results of the water quality observations from sampling boats on 27 September and 3 October showed that surface salinity along the northern shore of Tokyo Bay increased from 25~26‰ on 27 September (Fig. 3.13 (a)) to more than 32‰ on 3 October (Fig. 3.13 (b)), indicating that high salinity water appeared at the surface along the northern shore during this period. Although the calculated surface salinity in this area showed an increase of only 2‰ on 27 September, the appearance of high-salinity water at the surface of northeastern shore on 3 October was simulated successfully (Figs. 3.14 (a), 3.14 (b)). Both observed and calculated results showed a salinity increase at the surface along the northern shore during this period (Figs. 3.13, 3.14). This change can be attributed to the upwelling and vertical mixing along the northern shore in Tokyo Bay caused by the northerly wind.

Dissolved oxygen was also measured on 27 September and 3 October. Observed dissolved oxygen at the surface along the northern shore was about 10 $mg.l^{-1}$ on 27 September (Fig. 3.15 (a)). However, it decreased to less than 3 $mg.l^{-1}$ on 3 October (Fig. 3.15 (b)). While observed dissolved oxygen at the bottom showed a minimum (*ca* less than 1 $mg.l^{-1}$) around St. A on 27 September (Fig. 3.16 (a)), the area showing a minimum value shifted to the northern shore on 3 October (Fig. 3.16 (b)). These data imply that anoxic bottom water moved northward and upwelled along the northern shore in the Awoshiwo event starting on 2 October.

The appearance of high-salinity and low-dissolved-oxygen water at the surface along the northern shore observed on 3 October indicates the occurrence of an Awoshiwo event.