Study on Numerical Analysis of Flow Characteristics and Mercury Dynamic Behavior in the Yatsushiro Sea and Minamata Bay

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In 1950s, Minamata Disease broke out due to the waste water with methylmercury compounds discharged into the coastal environment from a chemical factory. After confirmation of the cause, many measures have been applied to restore the coastal environment and protect the health of inhabitant. Through many countermeasures such as the Minamata Bay Pollution Prevention Project (MBPP) during 1977-1990, mercury concentration in Minamata Bay has dramatically decreased, and most of the mercury species and past distributions are known. But the dynamic behavior of mercury are still not completely understood and the quality of water containing mercury couldn't be accurately predicted in Minamata Bay. Therefore, in this paper flow characteristics including flow current, salinity and temperature fields in the Yatsushiro Sea are simulated by Princeton Ocean Model (POM), and 3D sediment transport model and pollution transport model based on the hydrodynamic model are established for the dynamic behavior of mercury in Minamata Bay. It aims to provide useful technical support for environmental management in the studied region and it is also a good example for mercury studies in the similar coastal environments.

Chapter 1 Introduction

Location of the Yatsushiro Sea and background of the Minamata Disease are introduced. Through summarizing the previous investigations and researches, objective and approach in this paper are described.

Chapter 2 Fluid Dynamics Theory and the Computation

Basic equations in fluid dynamic theory are deduced in different coordinates. Several popular models in computational fluid dynamics are summarized. In particular, Princeton Ocean Model (POM) which is used in this paper is introduced in detail.

Chapter 3 Numerical Analysis of Flow Field

Firstly a large model covering all of the Ariake Sea and the Yatsushiro Sea is established by POM. Uniform orthogonal grid is used with the number of 438×468. The grid interval is about 260 m. Ten layers are divided in the vertical direction. Lunar semi-diurnal tide (M_2) constituent of tidal motion is applied in south side of the area as the open boundary condition. Secondly in order to discuss other factors influencing on flow field, wind stress and river's outflow are added as boundary conditions, respectively. Then through utilization of tide prediction method, harmonic constants of four tidal constituents (M_2, S_2, K_1 and O_1) are applied in simulation. Effect of different horizontal

differencing scheme in baroclinic term on flow field is estimated in both winter and summer. Finally, a small model considering only the Yatsushiro Sea is adopted with non-uniform orthogonal grids of 304×327×10. The minimum horizontal grid interval is about 50 m around Minamata Bay and the maximum is about 260 m. Flow fields under two different topographies (before and after MBPP) are simulated and tidal ellipses at ten sites around Minamat Bay under different topography are analyzed.

Chapter 4 Distribution of Salinity and Temperature Fields in Summer Season

Based on measured data at 20 stations in the Yatsushiro Sea from cruises during 1977-2009 by Kumamoto Prefecture, distribution of measured salinity and temperature are analyzed. Salinity fields in six cases are simulated under the discharge from a A-Class river (the Kuma River) on basis of the large hydrodynamic model using M_2 constituent. Then a watershed model for two B-Class rivers (the Komenotsu River and the Minamata River) are combined into POM in two cases. Temperature fields in the same six cases are reproduced by the large model considering freshwater from all three rivers and M_2 constituent as boundary conditions. To increase the precision, four kinds of heat fluxes are calculated and employed in the surface boundary for the simulation of temperature field. At last, four constituents (M_2, S_2, K_1, O_1) together with three rivers, heat fluxes and rainfall rate are considered to simulate both salinity and temperature fields in the Yatsushiro Sea.

Chapter 5 Sediment Transportation in Minamata Bay

A 3D model for sediment transport is built to reproduce the distribution of sediment. The model covers only the Yatsushiro Sea and focus on Minamata Bay. The well known Stokes' formula is applied to compute the settling velocity of sediment. Bottom boundary condition includes both erosion and deposition processes. Measured concentration of clay with the diameter of 4 μm at our observation tower in Minamata Bay are utilized to verify the sediment transport model, and distributions of clay are simulated under two different topographies (before and after MBPP).

Chapter 6 Mercury Dynamic Behavior in Minamata Bay

As the initial trial calculations in Minamata Bay, a 3D pollution transport model for mercury cycling is established and coupled with the hydrodynamic model of POM and the sediment transport model. It considers: chemical reactions of dissolved mercury (oxidation, reduction, methylation, and demethylation); wet deposition of dissolved mercury; exchange between dissolved mercury and particulate mercury (desorption and sorption); and re-suspension/deposition of particulate mercury with suspended solid. After verification of the pollution transport model, mercury budget in Minamata Bay is estimated, and sensitivity analysis of the model is implemented to clarify the importance of different parameters in model.

Chapter 7 Conclusions

Results in this paper are discussed, and future directions are summed up which should be considered to improve the current research.