Benchmark tests for hydrodynamic simulation of coastal waters using Delft3D-FM

Hao Cao¹, Saiyu Yuan², Hongwu Tang², Joseph Hun-wei Lee³
1. College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing, China
2. State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China
3. Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

ABSTRACT

In coastal waters, algal blooms (the rapid growth of microscopic phytoplankton) are often observed. The resulting oxygen depletion and even poisoning make local fisheries suffer severe damages. The dynamics of harmful algal blooms (HABs) are poorly understood. Novel models applying unstructured grids, e.g. Delft3D Flexible Mesh (Delft3D-FM), offer a good tool for a better representation of the hydrodynamics of coastal waters. In this paper, the performance of Delft3D-FM in hydrodynamic simulation of coastal waters was examined by a series of benchmark tests. The computational results were compared with analytical solutions or laboratory findings. At the end, the simulated tidal flushing processes in Hong Kong harbours were compared with previous studies.

KEY WORDS: Delft3D-FM; coastal waters; hydrodynamics; flushing processes; benchmark tests.

INTRODUCTION

In subtropical coastal waters around Hong Kong of China, algal blooms are often observed. Harmful effects caused by algal blooms include dissolved oxygen depletion, fish kills, shellfish poisoning, and beach closures. In April 1998, a devastating red tide initiated in Mirs Bay resulted in the worst fish kill in Hong Kong's history - over 80% (3,400 tones) of fish stocks in HKSAR were wiped out, with an estimated loss of over HK$312 million. More recently, a severe algal bloom event started in Tolo Harbour in December 2015 and lasted for two months, resulting in fish kills and threats of spreading to outer Mirs Bay and Southern Waters. Despite significant upgrades of the water pollution control infrastructure over the past two decades, red tides and HABs still occur frequently in Hong Kong and present formidable challenges to fisheries management.

The team is working on setting up an early warning system for HABs. As the core of the forecast and management system, the tidal circulation and transport of pollutants are determined by hydrodynamics. A 3-D hydrodynamic model using structured grids, i.e. Delft3D, has been applied and validated for Hong Kong waters before (Lee and Qu, 2004). To provide a better representation of the irregular coastlines including that of islands, an unstructured-grid model (Delft3D-FM) is attempted to be adopted. In this paper, the performance of Delft3D-FM in hydrodynamic simulation of coastal waters was examined by a series of benchmark tests. The computational results were compared with analytical solutions or laboratory findings. At the end, the simulated tidal flushing processes in Hong Kong harbours were compared with previous studies using Delft3D.

BENCHMARK TESTS

The coastal waters are characterized by periodic tidal currents, diffusion of saline water, mixing with fresh water, and so on. While the coastlines are of complex geometry, the structured curvilinear grid cannot accurately reproduce the hydrodynamics in the near field and the corresponding mass transport. A novel flexible-mesh model developed by Deltares is attempted to simulate coastal waters around Hong Kong. The objective is to obtain a more accurate tidal flushing process in the semi-enclosed harbor and the corresponding flushing rate which is one of the key parameters for our fishfarm water quality model. Three benchmark tests were selected according to the dominant processes in semi-enclosed harbours, including: (1) Long wave propagation in a semi-enclosed channel; (2) Pure diffusion of finite source; (3) Salinity intrusion in an estuary.

Case 1: Long wave propagation in a semi-enclosed channel

Analytical solution. The hydrodynamics of coastal waters is dominated by periodic tidal forcing. The phenomenon of standing wave and its propagation is distinguished. To verify the propagation of long wave in a semi-enclosed channel, the shallow water equations were linearized as in Lynch and Gray (1978). Three assumptions have been made: (1) The convective terms are neglected; (2) The oscillations of the free surface are small in comparison to the total depth; (3) A linearized friction term is used. The governing equations take the form:

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