Flood-tide interaction numerical simulation at Min River tidal reach

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Abstract

Flood and tide features at Min River tidal reach are analyzed and a high-resolution flood-tide coupled model which uses high-resolution GIS data for Minjiang Estuary with the highest grid resolution of 50-100m at key areas is established in this paper. Unstructured triangular mesh that can realize the grid resolution of 50-100m at key areas is employed in the model. Zhuqi section is chosen for flood boundary, and three numerical experiments are conducted for June 6 2006 flood process. The experimental results indicate that, when coupled with tide and flood, the simulation of each tide gauge agrees very well with measured data compared with model results only with flood or tide, and the original tidal features are changed at the different sections in Min River tidal reach by the flood signals. Obvious flood characteristics are shown in Wenshanli and Jiefang Bridge station and flood-tidal mixed characteristics are shown in Xianan, Baiyantan and Guantou station. The strong interaction between tide and flood occurs in the watercourse (from Xiannan in South Channel to Guantou) because the current velocity is reduced during high water time but increased during low water time.

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Selection and peer-review under responsibility of IUTAM Symposium on Storm Surge Modelling and Forecasting.

Keywords: Min River tidal reach; ADCIRC 2D model; high resolution; flood-tide interaction

1. Introduction

Min River is the largest river in Fujian Province, which originated in the Wuyi Mountain that is located at the junctional zone of Fujian, Jiangxi and Zhejiang provinces. The three major confluents including Shaxi River, Jianxi River and Futunxi River at Nanping flow into upstream of Min River, and then Min River flows from west to east into the East China Sea.

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Zhuqi hydrological station is an important hydrological research station which is located at the downstream of Min River with 54500km$^3$ catchment area$^{1, 2}$. Min River tidal reach is often suffered flood disasters. More than tenserious floodsdisasters which caused large numbers of people affected and economic losses since 1949 happened at Min River tidal reach according to Zhuqi hydrological data$^{3, 4}$. Therefore, flood research and flood-tide interaction in Min River tidal reach are important subjects.

### 2. Flood-tide coupled model

#### 2.1. Equations and parameters setting

ADCIRC solves forms of the shallow-water equations (SWE) for water levels and the vertically-integrated momentum equations for currents. The model applies the continuous-Galerkin finite-element method with linear triangular elements to discretize and solve the SWE on unstructured meshes, and thus it allows localized refinement in regions where the solution gradients are large. The temporal discretization is different for the continuity and momentum equations. For the continuity equation, the time derivatives are discretized over three levels, so that the solution for the future water level requires knowledge of the present and past water levels. For the momentum equation, the temporal discretization is explicit for all terms except Coriolis, which uses an average of the present and future velocities$^5$. At every geographic mesh vertex, ADCIRC solves for the water level and the two components of the current at an interval of 1s, the time step in this paper.

The continuity equation is

$$\frac{\partial \zeta}{\partial t} + \frac{1}{R \cos \phi} \frac{\partial UH}{\partial \lambda} + \frac{1}{R \cos \phi} \frac{\partial VH}{\partial \phi} - \frac{VH \tan \phi}{R} = 0. \quad (1)$$

The momentum equations are

$$\frac{\partial U}{\partial t} + \frac{U}{R \cos \phi} \frac{\partial U}{\partial \lambda} + \frac{V}{R \cos \phi} \frac{\partial U}{\partial \phi} - \frac{(U \tan \phi)}{R} + fV = -\frac{1}{R \cos \phi} \frac{\partial}{\partial \lambda} \left( \frac{p_s}{\rho_0} + g(\zeta - \eta) \right) + \frac{\tau_{s\lambda} - \tau_{b\lambda}}{\rho_0 H} + D_\lambda, \quad (2)$$

$$\frac{\partial V}{\partial t} + \frac{U}{R \cos \phi} \frac{\partial V}{\partial \lambda} + \frac{V}{R \cos \phi} \frac{\partial V}{\partial \phi} + \frac{(U \tan \phi)}{R} + fU = -\frac{1}{R \cos \phi} \frac{\partial}{\partial \phi} \left( \frac{p_s}{\rho_0} + g(\zeta - \eta) \right) + \frac{\tau_{s\phi} - \tau_{b\phi}}{\rho_0 H} + D_\phi. \quad (3)$$

where $\lambda, \phi$ are the longitude and latitude, $H = \zeta + h$ is the total water depth, $\zeta$ is the deviation of the water surface from the mean, $(U, V)$ are the depth-integrated currents, $R$ is the radius of the earth, $f = 2 \Omega \sin \phi$ is the Coriolis parameter, $\Omega$ is the angular velocity of earth rotation, $g$ is the gravitational acceleration, $P_s$ is the atmospheric pressure at the surface, $\rho_0$ is the reference density of water, $\eta$ is the Newtonian equilibrium tidal potential, $\alpha$ is the effective earth elasticity factor, $(\tau_{s\lambda}, \tau_{s\phi})$ are the surface stresses, $(\tau_{b\lambda}, \tau_{b\phi})$ are the bottom stresses, and $D_\lambda, D_\phi$ are the momentum dispersion terms.

Initial conditions: $\zeta = u = v = 0$.

Land boundary conditions: normal velocity is equal to zero.

Open boundary conditions: there are 8 tidal constituents($M_2, S_2, K_2, N_2, K_1, O_1, P_1, Q_1$) whose harmonic constants obtained from the global tidal model NAO09.

For this study, the hybrid bottom friction function is used. The form is more accurate in shallow water and when wetting and drying of elements are allowed. The quadratic bottom friction equation that is used with the hybrid bottom friction formulation is defined as:

$$\tau_h = C_f \frac{(U^2 + V^2)^{1/2}}{H}, \quad (4)$$
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