

Case Study on Numerical Prediction Model of Typhoon and Storm Surge at Yangtze Estuary in Shanghai

Xiao Mengjie, Sun Li, Pan Chonglun, Qiu Shaowei, Chen Sheng

Shanghai Flood Control Information Center, Shanghai 200050, China

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Abstract: In order to effectively improve the accuracy of storm surge numerical prediction, a numerical prediction model of typhoon tide in the Yangtze River estuary was constructed based on the study object of coastal area of the Yangtze River estuary in Shanghai. The model can simulate the changing process of the tidal level under the influence of multiple factors such as storm surge and astronomical tide. In order to verify the model, the super typhoon "Talim" No. 1718 was selected as a typical case, and the tracing prediction was conducted on storm water increase caused by this typhoon. It has been verified that the central position of the Typhoon "Talim" is 400km away from the coast of Shanghai, and does not cause storm water increase above 1.0m; and the average mean square error of the predicted tide level is 0.11m, and the forecast accuracy is good, which can meet the storm surge forecasting requirements.

1. Introduction

The storm surge is an abnormal rise and fall of the sea surface caused by strong winds and sudden changes in air pressure accompanied with strong atmospheric disturbances. In terms of cause of formation, storm surges can be divided into typhoon surges caused by tropical cyclones (or typhoons) and cold wave storm surges caused by extratropical cyclones (or cold air). If the astronomical tide happens during the storm surge, it may cause a sharp increase in the water level on the shore, which will seriously affect the production and construction of the coastal areas and even cause huge loss of life and property.

Located at the Yangtze estuary the middle of China's mainland coastline, Shanghai is not only the economic, financial, trade and shipping center of mainland China, but also an emerging tourist destination and one of the areas frequently affected by disaster of storm surges. With the rapid development of social economy in Shanghai, preventing and mitigating the disaster of storm surges is an important task in building a harmonious society and implementing a sustainable development strategy. In view of the indefinite loop of intrusive cyclone, wide range of influence, and complex natural conditions in Shanghai, it is necessary to conduct simulation research on the numerical prediction model of storm surge in Shanghai coastal area, provide storm surge forecasting results in time, and provide technical support for water situation consultation.

2. Numerical prediction model of storm surge in the Yangtze Estuary

2.1 Basic equation

The water depth in offshore is generally shallow. The large-scale water movement caused by the strong wind of the typhoon can be roughly assumed to be uniform between the upper and lower layers, so a two-dimensional model along the deep integration (or average) can be used^[1,2].

Complete deep-depth integrated two-dimensional full-flow basic equation:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad (1)$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left(\frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left(\frac{MN}{D} \right) = -gD \frac{\partial(\zeta - \zeta_0)}{\partial x} + \frac{\tau_s^x - \tau_b^x}{\rho_w} + fN \quad (2)$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left(\frac{MN}{D} \right) + \frac{\partial}{\partial y} \left(\frac{N^2}{D} \right) = -gD \frac{\partial(\zeta - \zeta_0)}{\partial x} + \frac{\tau_s^y - \tau_b^y}{\rho_w} - fM \quad (3)$$

$$M = \int_{-h(x,y)}^{\zeta(x,y)} u(x, y, t) dz \quad N = \int_{-h(x,y)}^{\zeta(x,y)} v(x, y, t) dz$$

In which, M, N are the full-flow components; $D = h + \zeta$, the full water depth, that is, the distance from the water surface to the seabed, h is the water depth under the average sea level, ζ is water level increases or decreases compared with averaged sea level; $f = 2\omega \sin \varphi$ is the coefficient of Coriolis force (Earth rotation inertial force), in which ω is the rotation angular velocity, φ is the geographic latitude of the water in the calculation, g is the gravitational acceleration; ζ_0 is the sea surface static pressure rise caused by the typhoon pressure drop, when the pressure distribution is taken from the Takahashi formula, $\zeta_0 = \frac{10^3 \Delta p}{\rho g}$, $\Delta p = p_\infty - p_0$, p_∞ is the typhoon peripheral pressure, and p_0 is the typhoon center pressure^[3].

2.2 Computational domain and mesh generation

The range of influence of typhoons is usually several hundred kilometers, and the domain of numerical calculations is relatively large. The storm surge forecasting model adopts grid embedded technology to meet the needs of large scale of typhoon influence and micro-topography of near-shore. The grid size of detailed model is 300m×300m. The model range western point starts from the Tiansheng port at inside of the Yangtze River estuary, out of the Yangtze River estuary it connects to the model of East China Sea. The model calculation domain is shown in Figure 1.

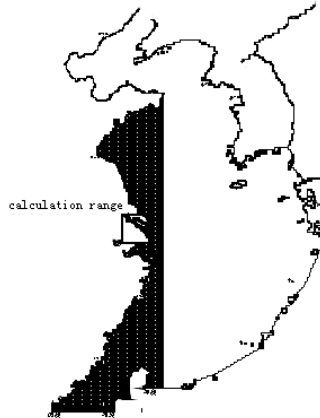


Fig.1 The large-scale computing domain and second-level grid range of East China Sea

2.3 Boundary conditions

The tide is not taken in account when calculating the boundary value at the water boundary of the typhoon water-increasing model, it is purely controlled by the static pressure of the moving typhoon pressure drop (transition disturbance)^[4]. The air pressure around the typhoon takes the average monthly pressure of the Chinese sea area. The boundary values on the interface of different size grids are exchanged based on the principle that "the water level of the small grid is supplied to the large grid, and the flow of the large grid is provided to the small grid", so that the calculation domain of different size grid can be calculated according to each slot time in respective area^[5,6].

2.4 Calculation of typhoon wind field

The wind speed at each point in the typhoon area consists of two parts, one is the wind speed related to the moving speed of the typhoon center; the other is the symmetrical gradient wind speed

related to the typhoon pressure gradient [7, 8].

Suppose that the moving speed of typhoon center is V and wind speed at 500km away from typhoon center decayed to $\exp(-\pi)^{[9]}$ caused by the movement of center, thus, the wind speed of each grid point associated with the movement of typhoon center is calculated as:

$$F = C_1 \cdot V \cdot \exp\left(-\frac{\pi \cdot r}{500}\right) \quad (4)$$

The coefficient C_1 is generally taken from 4/7 to 6/7. For a typhoon with a large R_1 , C_1 takes 4/7; when the typhoon range is small, C_1 takes 6/7 [10].

3. Case Study of the Storm Surge in the Yangtze Estuary

Based on the characteristics of typhoon movement and the influence of astronomical tides, the 1718 super typhoon “Talim“, which affects Shanghai in 2017, was selected as a typical typhoon to calculate the water increase caused by storm surge in the Yangtze River estuary. In addition, when this typhoon happened and affected Shanghai, it coincided with astronomical climax.

3.1 Typhoon Overview

In 2017, there was one typhoon affecting Shanghai, which was the super typhoon “Talim“ of No. 1718, and the typhoon path is shown in Figure 2. The typhoon was formed on the ocean surface at distance about 2380 km from east of Manila, Philippines at 21:00 on September 9, 2017. At 02:00 on September 11, the Central Meteorological Observatory upgraded it to a strong tropical storm; at 20:00 on September 11, it was upgraded to a typhoon; at 18:00 on September 12, the Central Meteorological Observatory issued an orange warning signal for the typhoon; at 14:00 on September 13, it was upgraded to a strong typhoon; at 15:00 on September 15, it was downgraded to a typhoon; at 17:00 on September 18, the Central Meteorological Observatory stopped numbering “Talim“ because it was converted into an extratropical cyclone near Hokkaido.

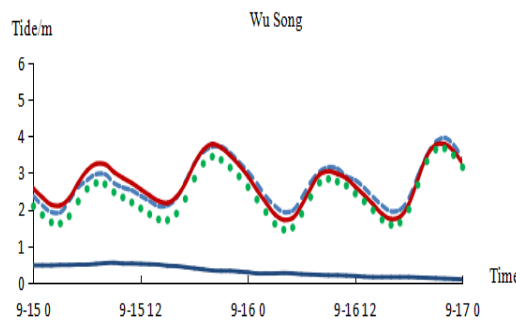


Fig.2 The path of typhoon "Tail" No. 1718

3.2 Calculation and analysis of storm surge water increase

Wusong, Gaoqiao, Luchaogang and Jinshanzui were selected as the representative stations to carry out the analysis of combined water increase caused by the wind field of typhoon “Talim“ No.1718 and the astronomical tide. The typhoon lasted for 9 days. During its development, the typhoon forecast path and the actual path showed large deviations. At 2 :00 on September 13, it predicted that the typhoon would turn at the sea surface 100 km away from east of Taizhou, Zhejiang; at 9 :00 on September 15, the typhoon center was 400km away from east of Shanghai, at that time the center pressure is 940 hPa and the wind speed was 50 m/s. During the typhoon happening, there were obvious tidal fluctuations in the waters of the Yangtze River estuary. The highest tidal level occurred around 9:00 on September 15. At this time, the water increase measured at near-shore observation station in Yangtze River estuary was about 50 cm, and the maximum water increase in Jinshanzui station was 67 cm. The forecast results of Gaoqiao, Wusong, Luchaogang and Jinshanzui five stations are shown below in Figure 3. According to statistics, the

forecasting error of the highest tide level of each tidal station is 0.11m, and the forecasting accuracy is good.

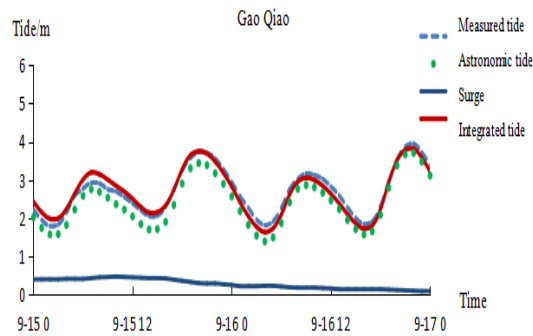


Figure 3 Tide level changing process of four stations during typhoon “Talim“

Figure 3 shows the distribution of storm surge elevation at 9:00 on September 15th. At this time, the maximum water increase of Wusong and Gaoqiao is formed. It can be seen from the figure that although the intensity of the typhoon “Talim“ reached a super-typhoon level during the active period, while the center position of the typhoon was 400km away from the coast of Shanghai, so it did not cause more than 1.0m storm water increase.

4. Conclusion

For the practical purpose of Yangtze River estuary to defense and mitigate typhoon disaster, it is extremely essential to conduct numerical simulation of typhoon storm surge in coastal areas of Shanghai. This paper based on the numerical model of typhoon storm surge in Yangtze River estuary, selects the No. 1718 super typhoon “Talim“ as a typical case, conducts tracing forecast of storm surge caused by the typhoon, and obtains the following conclusions:

(1) Typhoon wind field is one of the key elements for accurate prediction of storm surge model. Further improvement of wind field prediction capability is the focus of future model research.

(2) The center of the Typhoon “Talim“ is 400km away from the coast of Shanghai, and has not caused more than 1.0m storm water increase.

(3) After experiment, the average mean square error of the predicted tidal level of the typhoon is 0.11m with the application of the numerical prediction model of the Typhoon storm surge in Yangtze estuary, and the forecasting accuracy is good. Therefore, this model can be used for analyzing tidal lever change under the combined action of typhoon and astronomical tide, which can meet the storm surge forecasting requirements.

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