Storm surge modelling by Delft3D FM – a case study in Shanghai area

Qian Ke[1], Jeremy Bricker[1], and Qinghua Ye[1]

[1]Dr.

November 22, 2022

Abstract

The coupled Delft3D Flexible Mesh (D3D FM) - SWAN model with an unstructured grid has been developed recently to simulate storm surge and waves; and another open source model, Telemac-Tomawac, has been widely used for storm surge and wave propagation simulation in coastal areas for more than 20 years. However, the choice of a hydrodynamic model for a specific area in terms of cost, efficiency and accuracy is often a dilemma at the beginning of a modeling project. The objective of this research is to examine the effects of two software packages in terms of accuracy and performance with a case study in the Shanghai area of China. Model performance has been assessed based on model configuration, model calibration, grid generation and computational efficiency. Comparing measured water levels with model results, both approaches were able to accurately predict hydrodynamic conditions in a complex estuarine environment. Both models showed that it can efficiently simulate hydrodynamics in the coastal area under various scenarios for further climate adaptation research. Additionally, both models were used to simulate inundation propagation due to hypothetical failures of flood defenses in the coastal area. A comparison of inundation extent and maximum inundation depth showed that they were equally well-suited for overtopping and inundation simulation.

Storm surge modelling by Delft3D FM – a case study in Shanghai area

Qian Ke[1], Jeremy Bricker[2], Qinghua Ye[3]
EGU, Vienna, April 2019

2019-3299

Background

East China Sea is one of the largest marginal seas in the western North Pacific Ocean, and is noted for its high levels of primary productivity and for the tremendous extent of river runoff into the sea, notably from the Yangtze River (Ichikawa & Beardsley, 2002). It has the flattest and widest continental shelf in the world, which is bounded to the north by a line running northeast from the northern edge of the Yangtze mouth to the southwestern tip of Korea, to the east of the Ryukyu islands chain and Kyushu, to the south by Taiwan, and to the west by the east coast of the mainland of China. Runoff, tides, winds, the continental-shelf current and topography are the main controls on hydrodynamic process in the Yangtze Estuary.

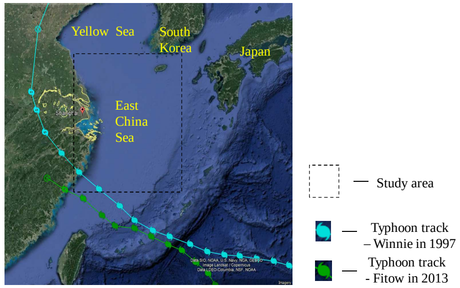

Fig. 1. Study area and typhoon tracks affect Shanghai area

Research Objective

- To set up a hydrodynamic model and to examine tides and storm surge during typhoon period in Yangtze Estuary and adjacent area.

Model set-up

➢Storm surge model

➢Computational unstructured grid

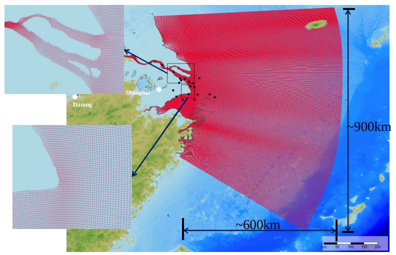

Fig. 2 Model domain and grids. Black dots represent tidal-gauge stations

Model set-up

➢Bathymetry

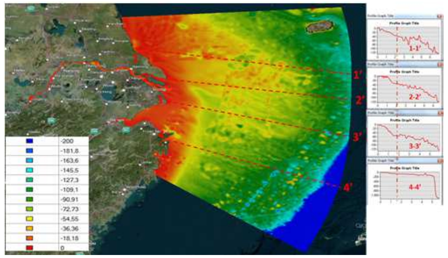

Fig.3 Bathymetry in the study area

➢Boundary conditions

Shallow topography adjacent to the river mouth causes denser co-phase lines and a reduction in the velocity of the tidal wave. In the Yellow Sea, the tide rotates with two nodal points, with the southern node having a dominant influence on the northern Yangtze Estuary.)). The boundary conditions were taken from the Yellow Sea Model (P.K. Tonnon, 2006).

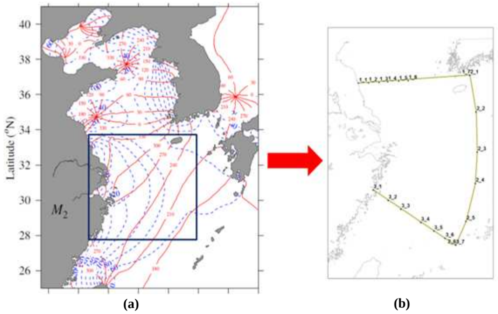

Fig. 4 (a) Distribution of the cotidal charts of M2 tide constituents in East China Sea (Wu et al, 2018) (co-amplitude with blue dashed line; co-phrase with red solid line); (b) open boundary geometry in the project domain

➢Other parameters

- Bottom roughness of manning coefficient : 0,026 in the sea and 0,012-0,022 in the estuary.
- Water density is 1025kg/m^3.
- Wind drag coefficient: $C_d^{(1)}$=0,0009839 at W_1 = 5 m/s
  $C_d^{(2)}$=0,002 at W_2 = 31,5m/s
  $C_d^{(3)}$=0,0008013 at W_3 = 60 m/s

Where C_d - wind drag coefficients ; W – wind speed

Model set-up

➢Typhoon model

Spatial-varing air pressure and wind fields were constructed using the parametric cyclone model by Holland(1980). The pressure fields are given by:

$$P(r) = P_c + \Delta P\, exp[-\left({}^{R_m}/_{r}\right)^B]$$

Where P(r) is the air pressure at radius r, $\Delta P = P_n - P_c$ is the pressure drop, P_c is the central pressure, P_n is the ambient pressure, R_m is the radius of maximum wind (RWM), and B is the hurricane shape parameter, which can be estimated by empirical relationships or taken as constant. In this study, P_n = 1013.25mbar, B = 1.563.

In case of no RWM data in the track information, the raltion of Tagaki and Wu(2016) is used to estimate this as Shown $R_m = 0.23 * r_{50}$, in which r_{50} is the radius of storm winds (50kt). The behaviour of typhoon Winnie in 1997 and Typhoon Fitow in 2013 were hindcase using typhoon data from JMA and JWTC, respectively. Since JWTC has R_m data for typhoon Fitow in 2013.
The wind fields are given by:

$$V(r) = \sqrt{\left({}^{R_m}/_{r}\right)^B V_{max}{}^2 \exp\,(1 - \left({}^{R_m}/_{r}\right)^B + r^2 f^2/4} - {}^{rf}/_{2}$$

Where V_{max} is the maximum wind speed , f is the Coriolis parameter.
Given typhoon parameter of ΔP and R_m, the wind and pressure fields are generated and imposed by means of a 'spiderwe'-like polar grid.

Results

➢Validation for Typhoon Winnie in 1997

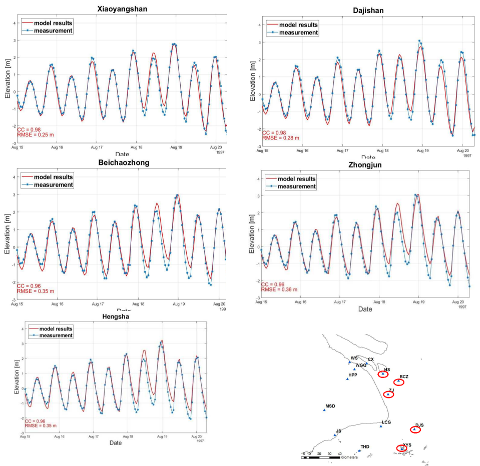

Fig. 5. Validation results compared with measurements (RMSE – root mean square error; CC – Correlation coefficient) during Typhoon Winnie in 1997

Results

➢Validation for Typhoon Fitow in 2013

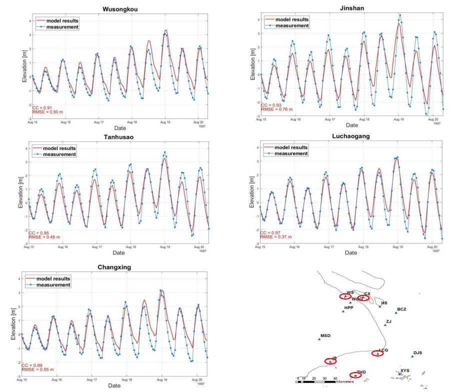

Fig. 6. Validation results compared with measurements during Typhoon Fitow in 2013

Conclusions

- Currently, the hydrodynamic model to examine the tide and storm surge have been set up, calibrated and validated;
- Bathymetry data and bottom roughness affect the model results significantly; updated annual bathymetry data is required in the study area if they're available.
- The storm surge could be more accurately modelled if the effect of waves is incorporated.

Authors

[1] Postdoc researcher, Department of Hydraulic Engineering, Delft University of Technology, Delft, the Netherlands, Q.ke@tudelft.nl
[2] Associate Professor, Department of Hydraulic Engineering, Delft University of Technology, Delft, the Netherlands, J.D.Bricker@tudelft.nl
[3] Senior Advisor/Researcher, Department of Hydraulic Engineering, Delft University of Technology and Deltares, Delft, the Netherlands, Qinghua.Ye@deltares.nl

References

Ichikawa, H., & Beardsley, R. C. (2002). The current system in the Yellow and East China Seas. Journal of Oceanography, 58(1), 77–92. https://doi.org/10.1023/A:1015876701363
P.K. Tonnon. (2006). Dongying Coastal model. WL/ Delft Hydraulics. Z4113.00
Wu, H.,Wu, T., Shen. J. et. al. 2018. Dynamics of the Changjiang River Plume. Coastal Environment, Disaster and Infrastructure – A case study of China's Coastline.
Holland, G. J. (1980), An analytical model of the wind and pressure profiles in hurricanes, Mon. Weather Rev., 108, 1212–1218

Acknowledgement

This work was supported by project of 'Sustainable Delta' funded by Netherlands Organization for Scientific Research NWO (ALWSD.2016.007).