The Response of Storm Surge with Different Typhoon Tracks in Jiangsu Coastal Areas

S. L. Zhao and D. A. Wu

***Abstract*—A study on the impact of different typhoon tracks on Jiangsu coastal storm surge has been conducted by setting up several experiments respectively directing at different typhoon tracks, including Typhoon offshore distance, landing angle and sites, and by using the numerical model of storm surge constructed based on the SELFE model. The study findings suggest that the maximum storm surges in coastal areas of Jiangsu decrease mainly with increasing offshore distance of typhoon tracks, and as the typhoon track moves away from the shore, the storm surge offshore will increase. With the increase of landing angle, the maximum storm surges in radial sand ridges would gradually decrease and those in the south of radial sand ridges in Jiangsu coastal areas will first increase and then decrease, and those in the north of radial sand ridges in Jiangsu coastal areas would remain unchanged and then decrease.**

***Index Terms*—Jiangsu coast, SELF model, storm surge, increase in water, typhoon track.**

I. Introduction

In recent years, the world has seen more frequent visits by storm surge and the gradually rising damages resulted therefrom, drawing extensive attention of the international community. [1]. To defense the storm surge and minimize the losses of such disaster, it's essential to warn and predict the storm surge and its time, location and tidal height [2], [3] timely and accurately for full preparations. So it is very urgent and significant for all coastal states to strengthen the discussion of storm surge's cause and the internal mechanism thereof, and study on the numerical model of storm surge [4] and increase accuracy of storm surge forecasting [5]. Therefore, a large scale ocean circulation model has been adopted in this paper to simulate and study the effect and physical process of the storm surge produced by typhoon in Jiangsu coastal areas to provide technical guidance for the development of these areas.

II. The Establishment and Verification

A. The Model and Its Simulation Range

The SELFE (Semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation) model is the most up-to-date ocean model developed by the Yinglong ZHANG, M. Baptista team [6]. The SELFE model, beinga maturity model, has been successfully adopted in respect to many problems of various estuary [7]. The V3.1d parallel version of the SELFE model has been used in this paper. The range for calculation in this model is 24 °N ~ 41 °N, 117 °E ~ 131 °E, including Bo Sea, Yellow Sea and East Sea. A trangle mesh distribution of the whole calculated ocean area has been shown in the Fig. 1 and those steep area close to the shore and in seafloor topography has been treated with mesh refinement. The resolution ratio of sea area in Jiangsu Coast in this paper is up to 100m and the boundary area between open waters and coastal waters is not less than 10km, including 154867 mesh nodes and 30544 triangular elements in the whole calculated area.

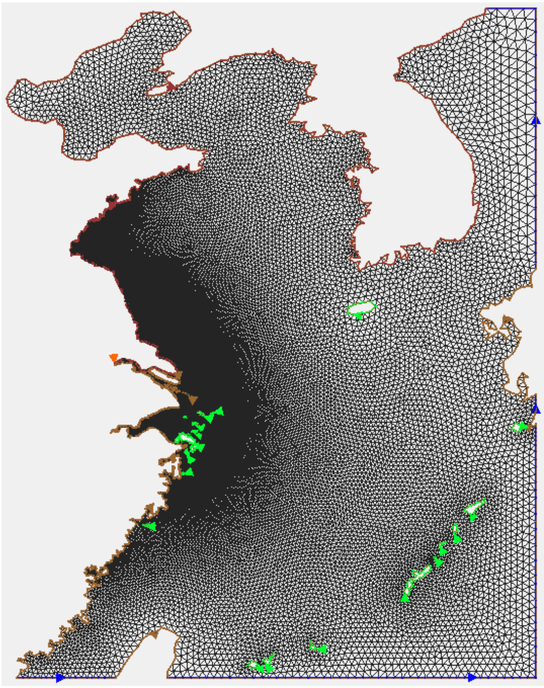

Fig. 1. calculated area and mesh distribution.

B. Boundary Conditions

The method of tidal harmonic constants in the given boundary nodes has been applied in open boundary conditions to drive the model. The harmonic constants of eight main partial tides (M2, S2, N2, K2, K1, O1, P1, Q1) from Japanese tide model has been interpolated into the open boundary nodes.

C. Correlation Parameter and Model Verification

The simulation time of the model is from zero o'clock, May 28th, 2011 to 23 o'clock, July 15th, 2011. The step of

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calculating time is set at 90 seconds and a result is output per hour. The drag coefficient of ocean area to be calculated is a comprehensive contributory factor relating to water depth, bottom morphology and water obstacles, etc. The drag coefficient field depending strongly on the depth of seawater has been given out according to the topography and sediment condition of the East China Sea. The chosen value after the calibration of the model is 0.001-0.0025. This paper first takes Muifa, the 9th tropical storm of 2011, to conduct simulation study [8]. The Typhoon wind field has been achieved through calculation with the model of Fujita air pressure and Miyazaki masae wind [9], which can be adopted to build the wind field of typhoon. By taking it as the atmospheric forcing in the model of storm surge, the simulation of the process caused by typhoons can be achieved; Furthermore, the data of wind field in netcdf format sourcing from ECMWF(http://apps.ecmwf.int/datasets/data/interim-full-daily/) is taken as the input wind field to simulate the process of storm surge. The result of the simulated sea level of the storm surge has been verified by comparison with the actual measured data, it demonstrates [10] that the sea level of the storm surge simulated by the two sets of wind field can more or less accurately reflect the process of storm surge in Jiangsu coastal areas; The basic structure of typhoons could be better reflected by the wind field built in a model of typhoon wind field.

III. THE RESPONSE CHARACTERISTICS OF STORM SURGE IN JIANGSU COASTAL AREAS

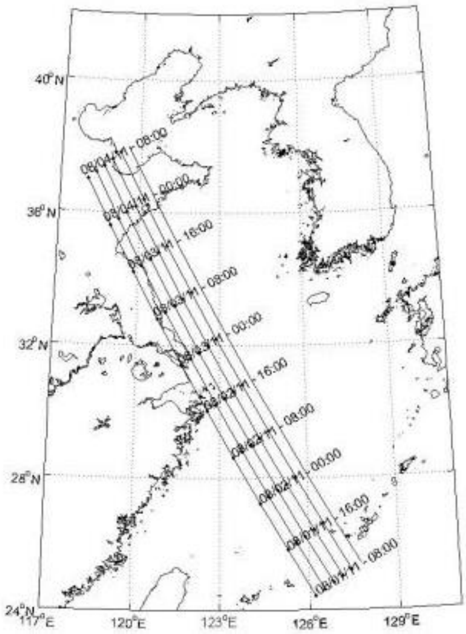


Fig. 2. The first experiment.

Given that the central air pressure, maximum wind speed radius, speed of typhoon center and other parameters are the same, then typhoon track will determine the size of storm surge elevation, the change of which may result in a totally different distribution pattern of storm surge. In order to study the influence that typhoon track has on storm surge in the Jiangsu coastal areas, 3 sets of experiments have been set up in this study, the tracks of which are shown in Fig. 2, 3 and 4 respectively(all of the typhoon centers are moving from low latitude towards high latitudes). Except for typhoon track, all the other characteristic parameters are identical, for example, the central air pressure is 970hPa, the maximum wind speed radius is 100km and the speed of typhoon center is 23km/h.

A. The Influence of Typhoon's Offshore Distance

In the first experiment shown in Fig. 2, the typhoon track is approximately parallel to the coastline in Jiangsu province with 40km of vertical spacing between every two tracks.

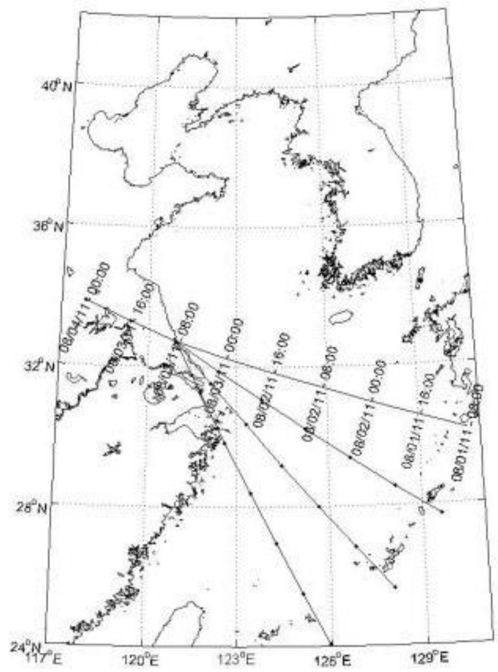


Fig. 3. The second experiment.

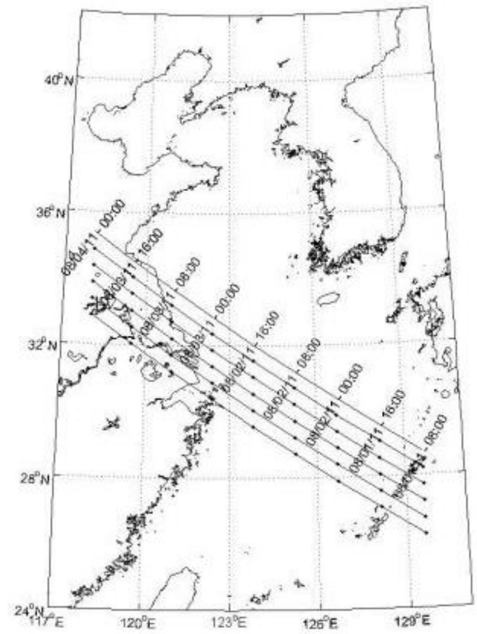
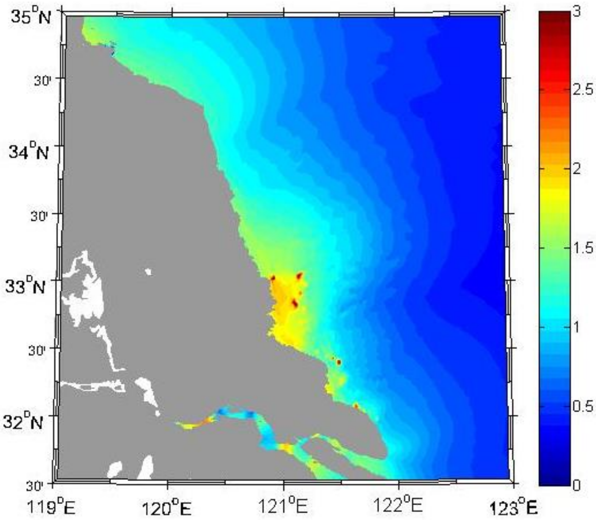


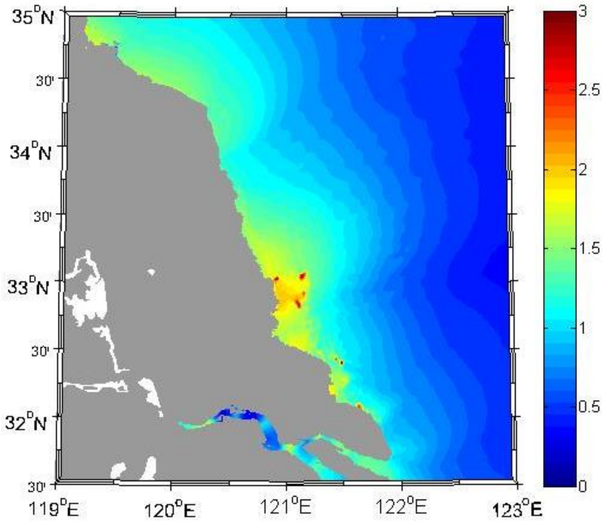
Fig. 4. The third experiment.

There are six tracks in total defined as the track 2-1 to 2-6 from west to east and the duration time of typhoon is from 8 o'clock, August 1st, 2011 to 8 o'clock, August 4th, 2011. Fig. 5 a-f represents the distribution of maximum storm surge produced in the process of track 2-1 to 2-6 of typhoon respectively.

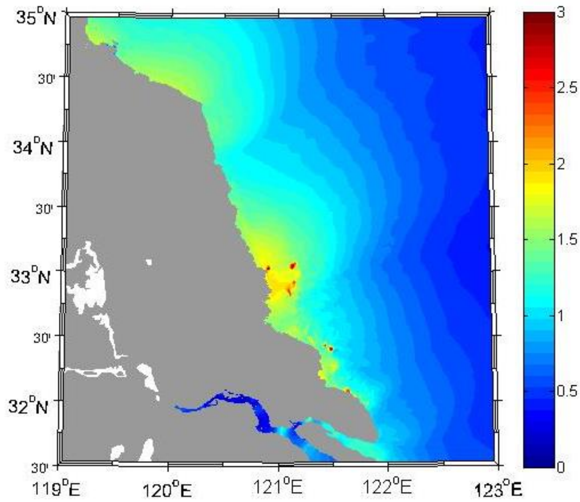
The track 2-2 typhoon basically moves roughly north along the coastline in Jiangsu province, producing the maximum storm surge near Jianggang in radial sand ridges with its peak value being up to more than 2m. The storm surge off the coast from Jianggang facing south to Lvsi is also great with its peak value being about 1.8m while the maximum storm surge in other places in Jiangsu coastal areas is mostly about 1.5m.



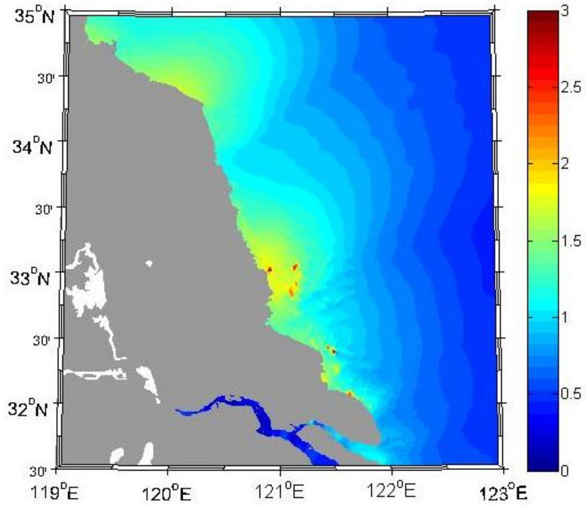
a) track 2-1



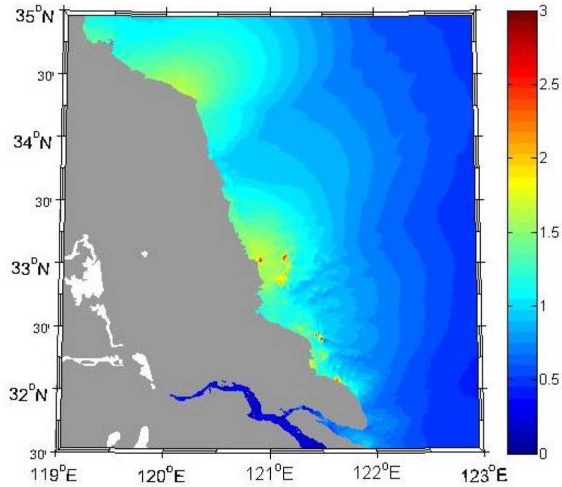
b) track 2-2



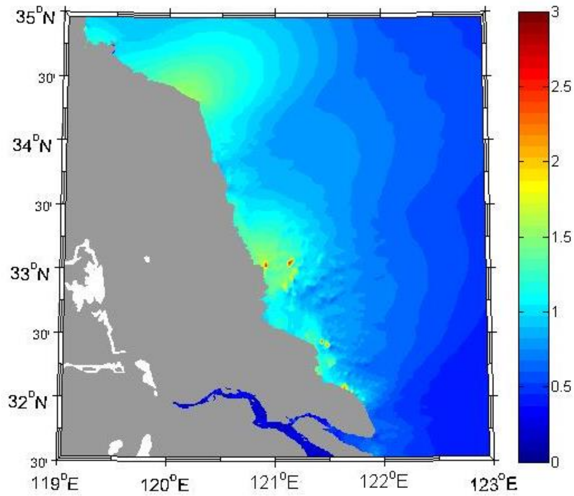
c) track 2-3



d) track 2-4



e) track 2-5



f) track 2-6

Fig. 5. The distribution of maximum storm surge in the first experiment.

The track 2-1 typhoon that is parallel to 2-1 landed in Yangtze Estuary and moves north along the coastline within 40km of Jiangsu coastline, results in the maximum storm surge near Jianggang greater than those in track 2-2 .The storm surge in the coast areas from Lianyungang to Binhai coastal has slightly decreased and no significant change in other coastal areas of Jiangsu. In the meantime, the storm surge elevation within the Yangtze Estuary of track 2-1 typhoon has markedly increased and the storm surge elevation far from the sea area has decreased.

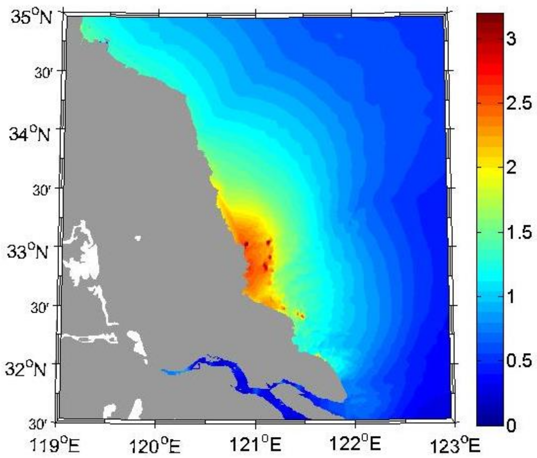
The track 2-3 moving north from about 40km beyond the Jiangsu coastline has caused the maximum storm surge near Jianggang to be slightly smaller than those caused by track 2-2 typhoon with less than 2m of maximum storm surge. The storm surge on the coast from Lianyungang to Binhai port has slightly increased and there is no significant change in other coastal areas of Jiangsu. The storm surge caused within Yangtze Estuary of track 2-3 has significantly decreased and the storm surge elevation far from the sea area has increased.

The track 2-4 around 80km beyond Jiangsu coastline has caused the maximum storm surge on the coast from Xiangshui to Binhai port which is slightly greater than those caused by track 2-3 typhoon and the maximum storm surge in other coastal areas of Jiangsu has decreased.

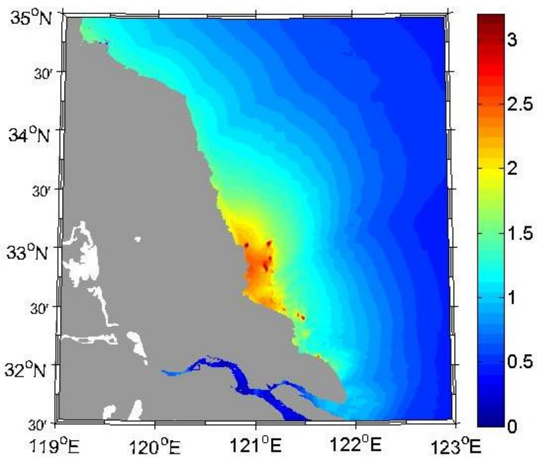
The maximum storm surge caused in the whole Jiangsu coastal areas has gradually decreased when the offshore distance of typhoon tracks continues to increase (track 2-5 and 2-6).

B. The Influence of Typhoon's Landing Angle

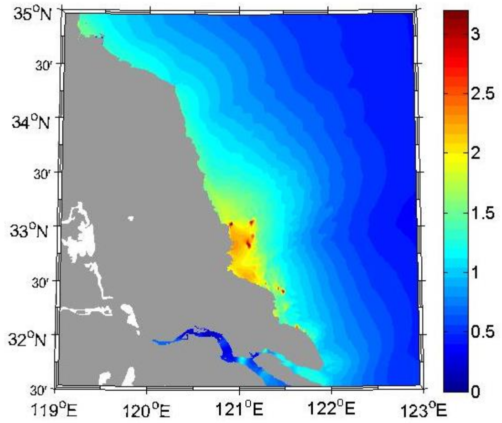
In the second experiment as shown in Fig. 3,there are four typhoon tracks from north to south that can be defined as track 3-1 to 3-4, and the angle between landing direction and the west in anticlockwise direction is 15 °,30 °,45 °and 60 ° respectively. All of which are landed in Jianggang ,Jiangsu province and then moves at an angle of 20 ° to the west and the duration of which is from 8 o'clock, August 1th, 2011 to 0 o'clock, August 4th, 2001.The distributions of maximum storm surge caused in the typhoon track 3-1 to 3-4 were shown in Fig. 6 a)-d).



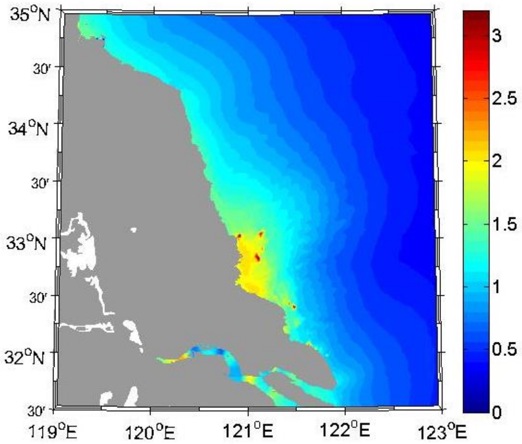
a) Track 3-1



b) Track 3-2



c) Track 3-3



d) Track 3-4

Fig. 6. The distribution of maximum storm surge in the second experiment.

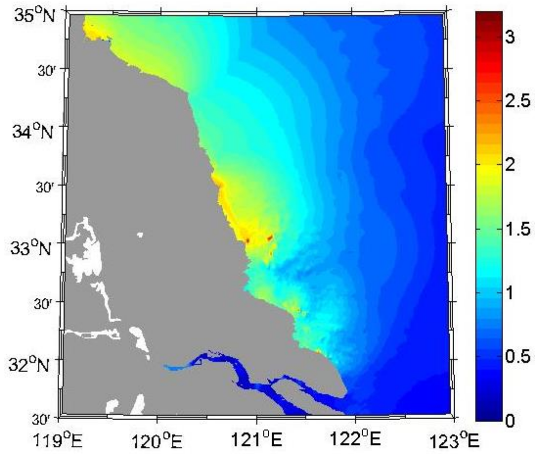
The track 3-1 landed in Jianggang at an angle of 15 ° to the west and produced the maximum storm surge near Jianggang in radial sand ridges with its peak value close to 2m while the maximum storm surge in other coastal places of Jiangsu is mostly about 1.5m.

The track 3-2 landed in Jianggang at an angle of 30 ° to the west and produced the maximum storm surge near Jianggang in radial sand ridges smaller than those spawned by track 3-1 with the peak value up to 2.5m or more. The maximum storm surge in the coastal places of southern Jiangsu has been increased and there is no significant change in other coastal areas of southern Jiangsu.

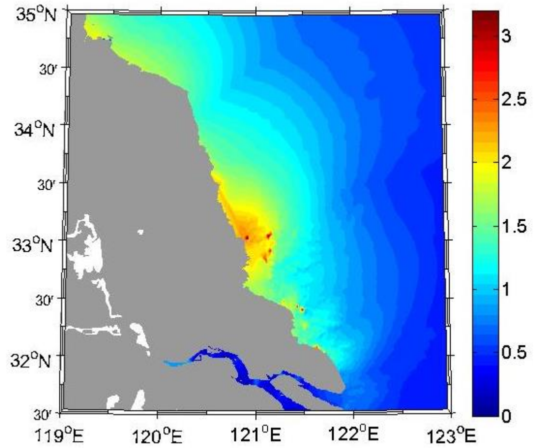
When the landing angle of typhoon continues to increase(track 3-3, 3-4), the maximum storm surges caused in the whole Jiangsu coastal areas has gradually decreased and those caused in Yangtze Estuary has increased significantly due to a closer distance between the typhoon and the Yangtze Estuary.

C. The Influence of Typhoon's Landing Sites

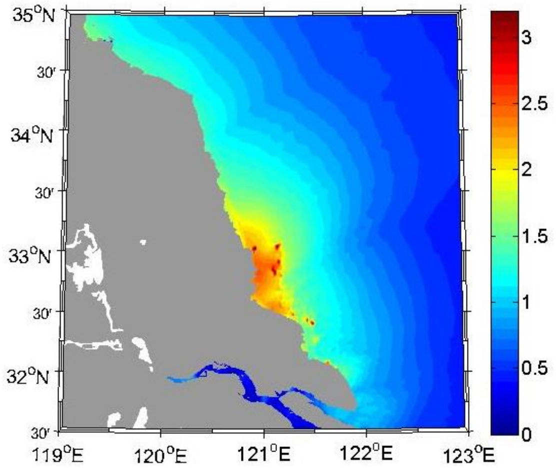
In the third experiment as shown in Fig. 4, all of the angles between landing direction and the west in anticlockwise direction are 30 ° with 55km of north-south spacing between every two tracks. There are six tracks from north to south which can be defined as track 4-1 to 4-6 respectively, during which track 4-3 landed in Jianggang with a duration of typhoon from 8 o'clock, August 1st, 2011 to 0 o'clock, August 4th, 2001.The distribution of maximum storm surge caused in the typhoon track 4-1 to 4-6 were shown in Fig. 7 a)-f).



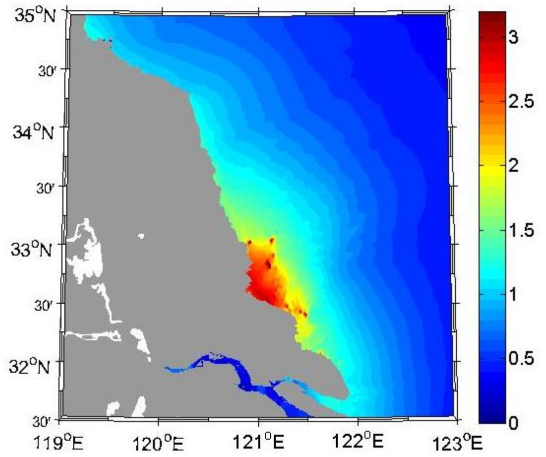
a) track 4-1



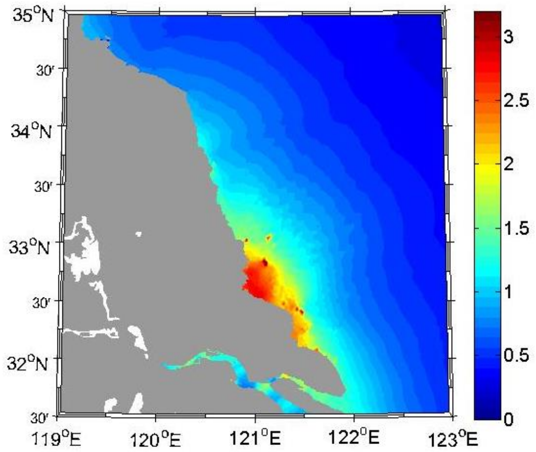
b) track 4-2



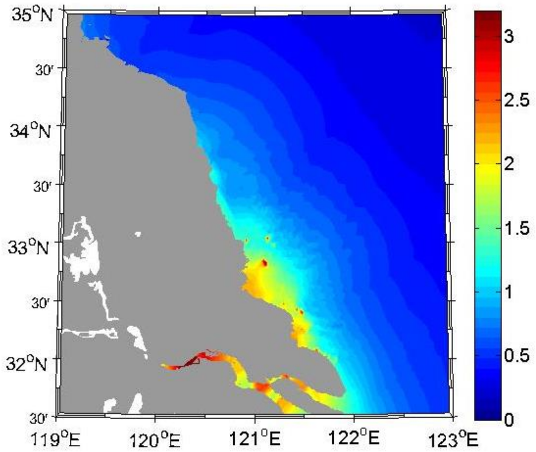
c) track 4-3



d) track 4-4



e) track 4-5



f) track 4-6

Fig. 7. The distribution of maximum storm surge in the third experiment.

When typhoon landed from low latitude to high latitude at an angle of 30 °to the west, apart from the greater storm surge caused by the convergence phenomena in the special topography of radial sand ridges, the storm surges in the area with the maximum wind speed radius to the north of typhoon's landing sites remained the most serious, this means that there would be the most serious storm surge when a typhoon landed within maximum wind speed radius to the south of a certain area. Because of the effect of the Deflection Force of Earth Rotation, the airflow on lower levels of typhoon in the Northern Hemisphere rotates counterclockwise round the eye of the typhoon. When typhoon landed back and forth, the wind speed north of the eye of typhoon is towards the shore, resulting in the storm surge elevation along the north coast area; while the wind speed south of the eye of typhoon is off the shore, resulting in the storm surge elevation along the south coast area.

IV. Conclusion

When the typhoon track is more or less parallel to Jiangsu coastline, it would cause the maximum storm surge near Jianggang in radial sand ridges. Moreover, because of the reflecting action of the Shandong Peninsula, the storm surge on the coast from Lianyungang in northern Jiangsu to Binhai port also has been increased. The maximum storm surge here has firstly increased and then decreased along with a longer offshore distance of the typhoon track. When the distance is close to the maximum wind speed radius, the storm surge reaches its peak value; the maximum storm surge in other coastal areas of Jiangsu decreased as the off distance of typhoon track increase. And with the offshore distance of typhoon track becoming longer, the storm surge elevation far from shore would have gradually increased.

The storm surge in Jiangsu coastal areas could be greater when the landing angle of typhoon landed in Jianggang is relatively small. With the increase of landing angle, the maximum storm surges in radial sand ridges would gradually decrease and those in the south of radial sand ridges in Jiangsu coastal areas will first increase and then decrease, and those in the north of radial sand ridges in Jiangsu coastal areas would remain unchanged and then decrease.

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Dr. Wu has been engaged in the research of the following projects recently such as, (1) "Research on the Dynamic Characteristics of Edge Wave in the Waters by Theoretical Solution and Numerical Simulation" for the National Natural Sciences Foundation of China. (2) "Research on Evaluation System and Key Technology of the Wetlands Evolution and Degeneration in Large River Mouth in China" for the Specialized Fund of Public Welfare Special Scientific Research Project Funded by China Ministry of Water Resources.