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Research article

Multi-factor assessment study of topographic changes and wind risk in the shallows of North Jiangsu Province based on satellite remote sensing and hydrodynamic modeling

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ABSTRACT

The North Jiangsu Province (NJP) shoal is the largest shoal sea area along the East China Sea coast, and the study of its topographic change and its impact on storm surge wind risk is of great significance for the development of coastal zone resources, environmental protection, and disaster prevention. In this study, we analyzed the multifactorial assessment of topographic changes and wind risk in the shallow shoals of NJP using satellite remote sensing and hydrodynamic modeling, and calculated the Simpson's wind index for the shallow shoals of NJP using the Improved Waterline Method and other methods, taking the shallow shoals of NJP as the study area. The results show that the topography of the shallows in NJP exhibits obvious inter-annual, seasonal and inter-monthly variations, showing a tendency of gradual decrease from the near shore to the far shore in the longitudinal direction, and a tendency of gradual increase from the south to the north in the transverse direction, with the presence of some complex topographic features in localized areas. The Simpson's wind hazard index of the NJP shoal has obvious spatial and temporal differences and variations, in which the Simpson's wind hazard index in the southern and central parts of the NJP shoal is higher than that in the northern part of the NJP shoal, reflecting that the intensity of wind hazards and the degree of risk are higher in the southern and central parts of the NJP shoal than in the northern part of the North Jiangsu Shoal. Research shows that storm surge events are one of the main drivers of topographic change and wind risk, and that factors such as the intensity, frequency, duration, and path of the storm surge affect the magnitude and distribution of wind risk. This study can provide some scientific basis and reference opinions for the topographic changes and tidal flats storm risk management in the shallow flats of NJP.

Keywords: storm surge; wind risk; satellite remote sensing; hydrodynamic modeling; Simpson's Wind Hazard Index; North Jiangsu Province Shoal

1 Introduction

Bathymetric and topographic data in coastal areas are an important basis for the study of the marine environment and resources, and with the development of marine science and technology, the methods for measuring these data are constantly advancing and innovating. In this paper, we take the North Jiangsu Province (NJP) shoal as the study area, and use multi-source data to analyze the spatial and temporal distribution and dynamic process of topographic changes in the NPJ shoal, as well as the mechanism and degree of influence of storm surge events on topographic changes [1-3]. This paragraph introduces the role and advantages of hydrodynamic modeling, providing data sources and processing methods for subsequent analysis. The intertidal region is a complex marine environment that includes two different terrain types, the permanently submerged area, which is covered by water all year round, and the intertidal zone, which is submerged or exposed with tidal changes. To accurately characterize these two terrain types, the terms bathymetry and topography will be used separately in this paper. Currently, the main methods for measuring bathymetry and topography in coastal areas are shipboard systems, spaceborne remote sensing and hydrodynamic modeling. Shipboard systems (e.g., single-beam and multibeam echosounders) are able to provide high-precision data, but are constrained by factors such as cost, manpower, difficulty of access to remote areas, and environmental conditions (e.g., low-tide navigational constraints). According to the World Health Organization (2020), bathymetry data for about 70% of the world's coastal areas need to be updated or lack detail (e.g., scale of 1:100). Remote sensing from space overcomes the limitations of traditional techniques and can provide bathymetric and topographic data for different environments, including areas that are difficult to measure, such as remote near-shore areas and vast intertidal zones. In shallow water (i.e., water depths between 0 and 15 meters), bathymetric data can be obtained by using imaging passive remote sensing with different algorithms for reflectance - a method called satellite-derived bathymetry (SDB). Hydrodynamic modeling is a method based on physical processes and mathematical models, which can simulate the flow field, water level, sediment transport, and other hydrodynamic parameters of the NJP shoal, and analyze the mechanism and effect of hydrodynamics on the change of topography of the NJP shoal, as well as the interactions and impacts of hydrodynamics on storm surges, topography, and other factors [4]. Hydrodynamic modeling has several advantages over other methods: first, it can provide continuous spatial and temporal distribution of data rather than discrete points or areas; second, it can consider the combined effects of multiple factors rather than the effects of a single factor; third, it can simulate and predict different scenarios rather than just reflecting the current state or history [5].

In order to explore the topographic changes of the shoal in NJP and their intrinsic connection with storm surge, and to provide scientific support for the sustainable development of the coastal zone [6]. This paper analyzes the spatial and temporal characteristics and patterns of the topographic changes in the shallows of NJP, as well as the mechanism and extent of the influence of storm surge events on topographic changes, using multi-source data, hydrodynamic models and other methods. This paragraph focuses on the different systems and methods used to measure the bathymetry and topography of the coastal area to provide data sources and processing methods for the subsequent analysis.

In addition to bathymetry and topography data, this paper also utilizes wind field data and wind hazard index data from the northern NJP shoal to analyze the impact of storm surge on topographic changes in the northern NJP shoal and the risk of wind hazard in the northern NJP shoal. Wind field data refers to the distribution of wind speed and direction along the coast, which is one of the most important factors affecting storm surge and one of the most important drivers of hydrodynamic modeling. In this paper, we use the ERA5 reanalysis wind field data provided by ECMWF (European Center for Medium-Range Weather Forecasts) with a resolution of 0.25 degrees, covering the whole domain of the shoal of NJP, with a time interval of 1 hour to ensure the real-time and integrity of the data. ERA5 Reanalysis of Wind Field Data is a methodology based on observational data and numerical models that provides high accuracy and resolution of wind field data on a global scale.

Using the Holland wind field analysis method, this paper analyzes the wind field characteristics of the storm surge in the shoal of NJP, such as the maximum wind speed, the maximum wind pressure, the radius of the wind field, etc., as well as the interactions and influences of the wind field with the storm surge and the topography of the terrain, etc. The Holland wind field analysis method is able to simulate the process and the results of the storm surge, to assess the intensity and the range of the storm surge, and to provide a basis for the assessment of the risk of the wind disaster.

Simpson wind hazard index is an index that integrates wind speed, wind direction, wind duration, storm surge water gain value and other factors, which can reflect the degree of damage and hazard of storm surge to coastal areas. In this paper, the Simpson wind hazard index data provided by the China Meteorological Administration are used to analyze the wind hazard risk of the shallow beaches in NJP, as well as the distribution and change of the wind hazard risk of the shallow beaches in NJP. The Simpson wind hazard index can synthesize the weights and influences of these factors and provide a basis for the assessment of the risk of wind hazards.

2 Data and methods

2.1 Description of the study area

The NJP shoal is located on the coast of Yancheng area, Jiangsu Province, between the Yangtze River Delta and the ancient Yellow River Delta. The shoal is about 200 km long and 90 km wide, with a total area of 22,470 km^2. Most of the shoals are below the sea surface, in which the area of dark sand accounts for 86% of the total area of shoals, and the underwater topography is complex and rapidly changing. The whole shoal, with the snare harbor as the apex, consists of more than 10 large submarine sand ridges, such as the Dongsha Sand Ridge, stretching out radially in the north, east and southeast directions, with a total of more than 70 shoals of various sizes. The length of each sand ridge is 10-100 km, and the width is 10-15 km. The water depth of the tidal channels developed between the sand ridges ranges from 10 to 30 m, and the maximum depth can reach 48 m.

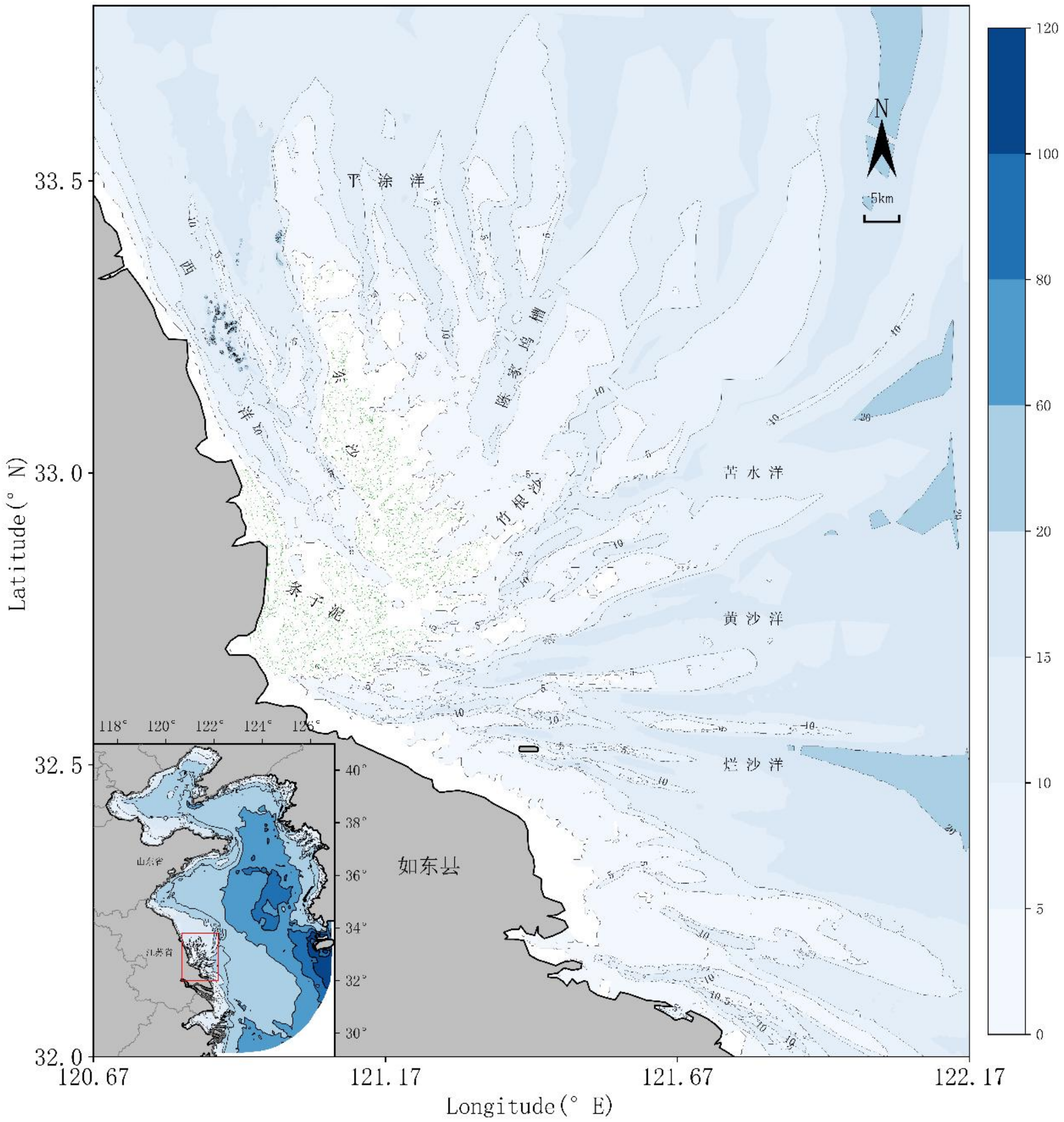

Fig.1 Image of the research area

2.2 Data sources

The period of study in this paper is from 2017 to 2021, and two typhoons were mainly selected to transit the shallow waters of northern Jiangsu, namely Typhoon Wimbia in August 2018 and Typhoon Heigbi in July 2020, respectively. Both typhoons were of strong tropical storm level or above, both were generated in the East China Sea and made landfall in Zhejiang or Shanghai, and both brought heavy rainfall and gusty winds to coastal and inland areas, and both caused serious disaster impacts. The intensity and frequency of their impacts on topographic changes and storm surges in the shallow north of Suzhou are typical and noteworthy study cases. Bathymetric remote sensing data is the basic data for this paper to study the topographic change of the shallow bank in North Jiangsu Province, and it is also one of the important input parameters for the hydrodynamic model. In this paper, Landsat 8 data and ICESat-2 data are utilized in combination with satellite-derived bathymetry (SDB) to obtain the bathymetric data of the shallows in NJP [7]. Landsat 8 is a high-resolution multispectral satellite jointly launched by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) that is capable of providing data at spatial resolutions from 15 to 100 m in 11 spectral bands covering the visible, near-infrared, and short-wave infrared ranges. ICESat-2 is a laser altimeter satellite launched by the National Aeronautics and Space Administration (NASA) of the United States of America, which is capable of providing data with a spatial resolution of 0.7 meters at a single wavelength of 532 nm, with global coverage of land and oceans [8]. SDB is a method of inverting water depth by utilizing the reflectivity of satellite images, combined with the optical properties of water bodies and the empirical relationship between water depth. In this paper, a neural network-based SDB method is used, which is able to automatically extract bathymetric information from Landsat 8 data, and at the same time utilize ICESat-2 data for correction and validation to improve the accuracy and reliability of bathymetric data [9-10].

Wind field data and wind hazard index data are the key data for this paper to study the impact of storm surge on the topographic change of the shallow beach in NJP, which is also an important basis for wind hazard risk assessment. In this paper, we use the TC optimal path dataset provided by China Meteorological Administration (CMA), combined with Holland's wind field analysis method and Simpson's wind hazard index method [11], to obtain the wind field data and wind hazard index data of the shallow beach in NJP. The TC optimal path dataset is the most accurate and complete TC dataset in the offshore region of China, which provides TC information covering parameters such as the latitude and longitude location of the TC center, maximum sustained wind (MSW), and minimum sea level pressure (MSLP) of the center every 3 or 6 hours in the northwestern Pacific Ocean from 1949 to the present [12]. Holland wind field analysis method is a method based on wind field data and numerical model, which can provide the wind field parameters of storm surge, and is used to assess the intensity and extent of storm surge. Simpson wind hazard index is an index that integrates wind speed, wind direction, wind duration, and the value of the storm surge water gain, which can reflect the degree of damage and the degree of hazard of the storm surge to the coastal area. In this paper, using the TC best path dataset, combined with Holland's wind field analysis method and Simpson's wind hazard index method, we calculated the wind field parameters and wind hazard index of the shoal of NJP, and analyzed the wind hazard risk of the storm surge on the shoal of NJP, as well as the distribution and change of the wind hazard risk of the shoal of NJP [13-14].

Hydrodynamic data is the core data of this paper to study the mechanism and effect of hydrodynamics on the topographic change of the shallow bank in NJP, and also the main data of the interaction and influence of hydrodynamics with storm surge and topography [15]. In this paper, the hydrodynamic model is used to simulate the hydrodynamic parameters of the shallow bank in northern Jiangsu, combined with the bathymetry remote sensing data, to analyze the mechanism and effect of hydrodynamics on the change of topography of the shallow bank in NJP, as well as the interactions and impacts of the hydrodynamics with storm surges, topography, and other factors [16]. Hydrodynamic modeling is a method based on physical processes and mathematical models, which can simulate the flow field, water level, sediment transport and other hydrodynamic parameters of the shallow beach in North Jiangsu [17-20]. In this paper, a hydrodynamic model based on the finite element method is used, which is able to adapt to the complex topography and boundary conditions of the northern Suzhou shoal, and at the same time, the bathymetry remote sensing data are utilized for calibration and validation to improve the accuracy and reliability of the hydrodynamic model [21-24].

2.3 Data processing methods

In this paper, satellite remote sensing technology is utilized to invert the bathymetry data of the NJP shoal. The bathymetry data is the basic data for the study of topographic change of the shallow bank in North Jiangsu Province, and it is also one of the important input parameters of the hydrodynamic model. In this paper, two satellite data, ICESat-2 and Landsat-8, are selected to provide the reflectivity information of the water body and the true value information of the water depth, respectively. ICESat-2 is a high-precision laser altimeter satellite data covering the global land and ocean, and Landsat-8 is a high-resolution multispectral satellite data covering the visible, near-infrared, and short wave infrared (SWIR) ranges. range. In this paper, the ATL03 point cloud data from ICESat-2 is used to filter out the signal photons at the water surface and seafloor to determine the seafloor elevation along the track. Comparison with airborne laser bathymetry data shows that the error and correlation of the seafloor elevation are within reasonable limits. Then, three semi-empirical functions, modified linear/polynomial/exponential ratio models, are utilized to fit the spectral data and ICESat-2 elevation data using the logarithmic ratios of band 3 and band 2 of Landsat-8 as the core. Using the trained model, the bathymetric inversion of Landsat-8 images is performed to obtain the bathymetric map. In this paper, using ICESat-2 data, the estimated data of bathymetry are corrected and validated, the accuracy and reliability of the bathymetry data are evaluated, and the final bathymetry remote sensing data are obtained.

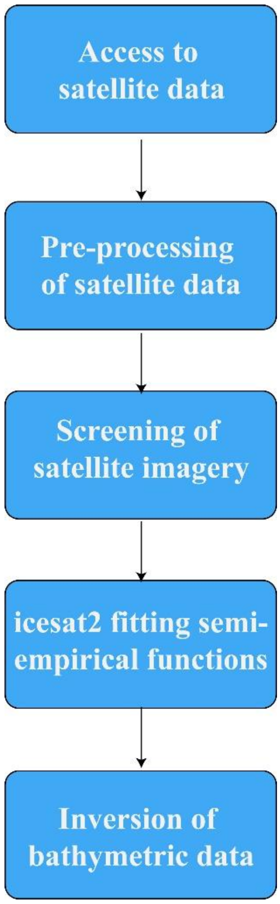

Fig.2 Water depth retrieval process by remote sensing

Using typhoon data and wind field analysis techniques, wind field data and wind hazard index data are extracted from the shallow beach in NJP. The wind field data and wind hazard index data are the key data for this paper to study the impact of storm surge on the topographic change of the NJP shoal, and they are also the important basis for the wind hazard risk assessment. In this paper, the TC best-path dataset is selected to provide the basic information of the typhoons in the shallow area of NJP. The TC best-path dataset is an accurate and complete TC dataset, which provides the TC information on the latitude and longitude location of the center of the TC, the maximum sustained wind speed, and the central minimum sea level pressure, and other parameters of the center of the TC in the Northwest Pacific Ocean for every 3 or 6 hours from 1949 to the present. In this paper, based on the Holland wind field analysis method and the Simpson wind hazard index method, the wind field parameters and the wind hazard index of the Shallow Shoal in the Northwest Pacific Ocean are calculated based on the basic information of the TCs. The Holland wind field analysis method is a method based on the wind field data and the numerical model, which is able to provide the wind field parameters of the storm surge for evaluating the intensity and range of the storm surge; the Simpson wind hazard index The method is a comprehensive consideration of wind speed, wind direction, wind duration, storm surge water gain value and other factors, which can reflect the degree of damage and hazard of storm surge to coastal areas. In this paper, the wind field data and wind hazard index data were corrected and verified by using the measured wind speed data, and the accuracy and reliability of the wind field data and wind hazard index data were evaluated, and the final wind field data and wind hazard index data were obtained. The acquisition and processing process of wind field data and wind hazard index data in this paper is shown in Fig. 3.

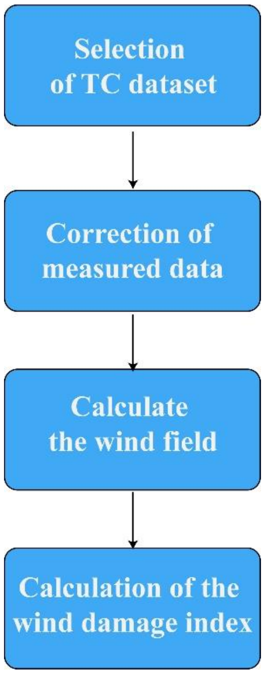

Fig.3 Calculation of wind field and wind disaster index

The hydrodynamic model and bathymetry remote sensing data are used to simulate the hydrodynamic parameters of the NJP shoal. The hydrodynamic parameters are the core data for this paper to study the mechanism and effect of hydrodynamics on the topographic change of the NJP shoal, and also the main data for the interaction and influence of hydrodynamics with storm surge, topography and other factors. In this paper, the hydrodynamic model of finite element method is chosen to provide the hydrodynamic parameters such as flow field, water level, sediment transport and so on in the shallow bank of NJP. The hydrodynamic model of the finite element method is a method based on physical processes and mathematical modeling, which can adapt to the complex topography and boundary conditions of the NJP shoal. In this paper, the boundary conditions and initial conditions of the hydrodynamic model are set using the remote sensing data of water depth, and the input parameters of the hydrodynamic model are obtained; the hydrodynamic model of the NJP shoal is calculated according to the input parameters of the hydrodynamic model by using the hydrodynamic model of the Finite Element Method (FEM) and the output parameters of the hydrodynamic model are obtained; the output parameters of the hydrodynamic model are corrected and verified by using the measured water level data and the sediment transportation data, and the output parameters of the hydrodynamic model are assessed and validated by the FEM. The output parameters of the hydrodynamic model were corrected and verified using measured water level data and sediment transport data, and the accuracy and reliability of the hydrodynamic model were evaluated, and the final hydrodynamic data were obtained. The acquisition and processing of hydrodynamic data in this paper are shown in Fig 4.

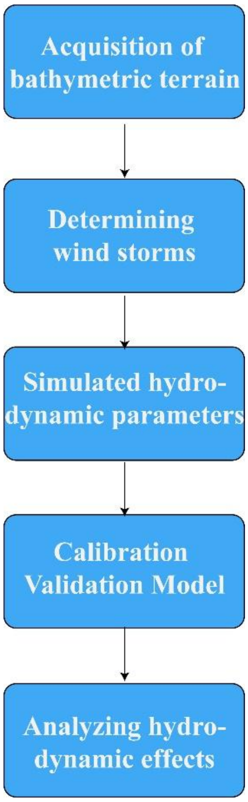

Fig.4 Hydrodynamic calculation process

3 Results and analysis

3.1 Results of remote sensing of bathymetry

For the study and also in order to study the relationship between storm surge and shoal topography, and then to further study the wind field and hydrodynamic modeling; six Landsat 8 OLI images before and after each of the two typhoon crossings from 2017 to 2021 were selected as the study objects. These two typhoons were Winnebago, which made landfall in August 2018, and Hagupit, which made landfall in August 2020, both of which were strong typhoon level storms that caused severe impacts on the shallow waters of NJP. The specific imaging time is shown in Table 1.

Tab.1 Landsat8 image transit date

Time period	Data volume	Image acquisition date	Data presentation
Before the Rumbia crossing	6	20171205, 20171221, 20180122, 20180207, 20180223, 20180327	Landsat 8 OLI Level 1 Collection2

After the Rumbia crossing	6	20180428, 20181021, 20181122, 20181224, 20190415, 20190821
Before the Hagupit crossing	6	20191024, 20191109, 20200112, 20200401, 20200519, 20200823
After the Hagupit crossing	6	20200908, 20200924, 20201111, 20201211, 20210114,20210216

In this paper, Landsat 8 OLI data are used for waterline extraction to analyze the characteristics of the shallow terrain in terms of scouring and siltation changes. Before waterline extraction, radiometric calibration and QUAC atmospheric correction of Landsat 8 OLI data are required to obtain physical quantities such as the true reflectance or radiance of the features and to eliminate the effects of factors such as the sensor itself and the atmosphere. Radiometric calibration is the conversion of raw digital quantization values (DN values) into radiometric brightness values or reflectance values, physical quantities that reflect the radiometric properties of a feature. The principle of radiometric calibration is to use the calibration parameters of the sensor, such as gain and offset, etc., to linearly transform the DN value to obtain the radiant brightness or reflectance value.

In this paper, satellite remote sensing technology is utilized to invert the bathymetry data of the NJP shoal. The bathymetry data is the basic data for this paper to study the topographic change of the shallow bank in NJP, and it is also one of the important input parameters of the hydrodynamic model. In this paper, two kinds of satellite data, ICESat-2 and Landsat-8, are selected, which provide the reflectivity information of the water body and the true value information of the water depth, respectively. In this paper, the ATL03 point cloud data from ICESat-2 is utilized to filter out the signal photons from the water surface and the seafloor to determine the seafloor elevation along the trajectory. Comparison with airborne laser bathymetry data shows that the error and correlation of the seafloor elevation are within reasonable limits. Then, three semi-empirical functions, a modified linear/polynomial/exponential ratio model, were utilized to fit the spectral data and ICESat-2 elevation data using the logarithmic ratios of band 3 and band 2 of Landsat-8 as the core (Eq. 1). Using the trained model, the bathymetric inversion of Landsat-8 imagery is performed to obtain a bathymetric map. In this paper, using ICESat-2 data, the estimated data of bathymetry were calibrated and validated to assess the accuracy and reliability of the bathymetry data, and the final bathymetry remote sensing data were obtained.

$$d = a + b\log\frac{R_{\lambda 3}}{R_{\lambda 2}} \qquad (1)$$

In order to get the topographic data of the shallows in NJP, this paper needs to further process the bathymetric remote sensing data. Since the bathymetric remote sensing data is based on the inversion results of satellite images, it is affected by the change of tide level and cannot directly reflect the real topography of the shoal. Therefore, satellite remote sensing technology was used in this paper to correct the bathymetry remote sensing data with tide level, which eliminated the influence of tide level change on the bathymetry data and obtained the topographic data of the shallows. Using satellite remote sensing technology, the sea surface height data of the shallow beach area in NJP was obtained, reflecting the change of tide level. Based on the sea surface height data, the bathymetric remote sensing data were corrected for the tide level, and the corrected bathymetric data were obtained. Then, this paper corrected the semi-empirical formula by using the logarithmic results of the elevation data of ICESat-2 and the band ratio of Landsat-8, and finally inverted to obtain the bathymetric data. With the elevation data of ICESat-2 and the measured bathymetry data, the bathymetry data obtained by inversion were corrected and verified, and the accuracy and reliability of the bathymetry data were evaluated, and the final bathymetry data were obtained. Fig. 5 shows the results of the bathymetric inversion of Landsat 8 OLI images before and after the passage of Typhoon Winnebago and Typhoon Hagupit.

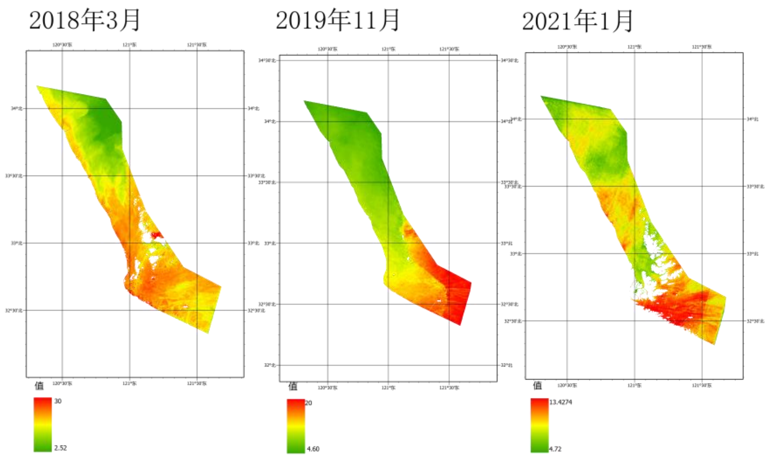

Fig.5 Topographic changes of Subei shoal before and after typhoon (remote sensing retrieval)

3.2 Calculation of Wind Field and Wind Hazard Index

In order to study the impact of storm surge on the topographic change of the shallow beach in NJP and the wind hazard risk of the shallow beach in NJP, this paper utilizes the wind field analysis technique to extract the wind field data and wind hazard index data of the shallow beach in NJP. The wind field data and wind hazard index data are the key data for this paper to study the impact of storm surge on the topographic change of the shallow beach in the NJP, and they are also the important basis for the wind hazard risk assessment.

In this paper, the TC optimal path dataset is selected to provide the basic information of the typhoons in the shallow region of NJP. The TC optimal path dataset is an accurate and complete TC dataset, which provides the TC information on the parameters such as latitude and longitude location of the center of the TC, maximum sustained winds, and the central minimum sea level pressure in the northwestern Pacific Ocean for every 3 or 6 hours from 1949 to the present. Two typhoons affecting the shallow north of Suzhou, Typhoon Winnebago (Wipha) in 2019 and Typhoon Hagupit (Haishen) in 2020, are selected as the research subjects of this paper. Typhoon Wipha, a strong tropical storm, was active near the shallow north of Suzhou from July 31 to August 3, 2019, with maximum sustained winds reaching 28.5 m/s and a central minimum sea level pressure of 985 hPa, while Typhoon Hegebi, a super typhoon, was active near the shallow north of Suzhou from September 4 to September 7, 2020, with maximum sustained winds reaching 67.5 m/s and a central The minimum sea level pressure was 915 h Pa. In this paper, the basic information of the typhoon provided by the TC optimal path dataset is utilized as an input parameter for the wind field analysis and the calculation of the wind hazard index.

Domestic and international research on typhoon wind field is based on the typhoon gradient wind field obtained from the barometric pressure field model calculations and superimposed on the typhoon center moving wind field unfolded in Eq. (2), that is:

$$V = V_m + V_g \quad (2)$$

Where V is the overall wind speed, Vm and Vg are the moving and gradient wind speeds, respectively. Currently, the models for calculating the moving wind speed are Jelesnianski and Ueno, etc., and the models for calculating the gradient wind speed are Holland and Jelesnianski, etc. Wang et al. compared the existing typhoon wind field models, and summarized that the Holland model can simulate the typhoon wind field better. Meanwhile, due to the independence of its maximum wind speed and wind profile parameter B, it is easy to simplify the calculation, so this paper adopts the Holland model and combines it with the parameterization scheme of typhoon wind field in East China Sea constructed by Wang et al. The empirical wind field model of the typhoon is also well practiced in the study of typhoon intensity in the East China Sea area.

Based on the TC optimal path dataset, the wind field parameters, including maximum sustained wind speed, maximum wind pressure, and radius of the wind field, are computed for the

Shallow Shoal in NJP before and after the two typhoon crossings. The principle of the Holland wind field analysis method is to use the parameters of the center position of the TC, maximum sustained wind speed, and minimum sea level pressure at the center, to build up a symmetric wind field model, and to use an exponential function to describe the attenuation of wind speed with the radius and use a constant to represent the angle of wind field deflection. A constant is used to represent the deflection angle of the wind field. Equation (3) of the Holland wind field analysis method is as follows:

$$V(r) = V_m (r / R_m)^B \exp\left[B(r / R_m - 1)\right] + fr\sin\phi \tag{3}$$

where V(r) is the wind speed at r from the center of the TC, V_m is the maximum sustained wind speed, Rm is the radius of the maximum sustained wind speed, B is the shape parameter of the wind field, f is the Koch parameter, and ϕ is the deflection angle of the wind field. In this paper, using V_m and Rm provided by the TC optimal path dataset, and B and ϕ estimated by empirical equations, the wind field parameters of the Shallow Shoal in northern Suzhou before and after the two typhoon transits are calculated, and the maximum wind speeds before and after the two typhoon transits are obtained, as shown in Fig. 6.

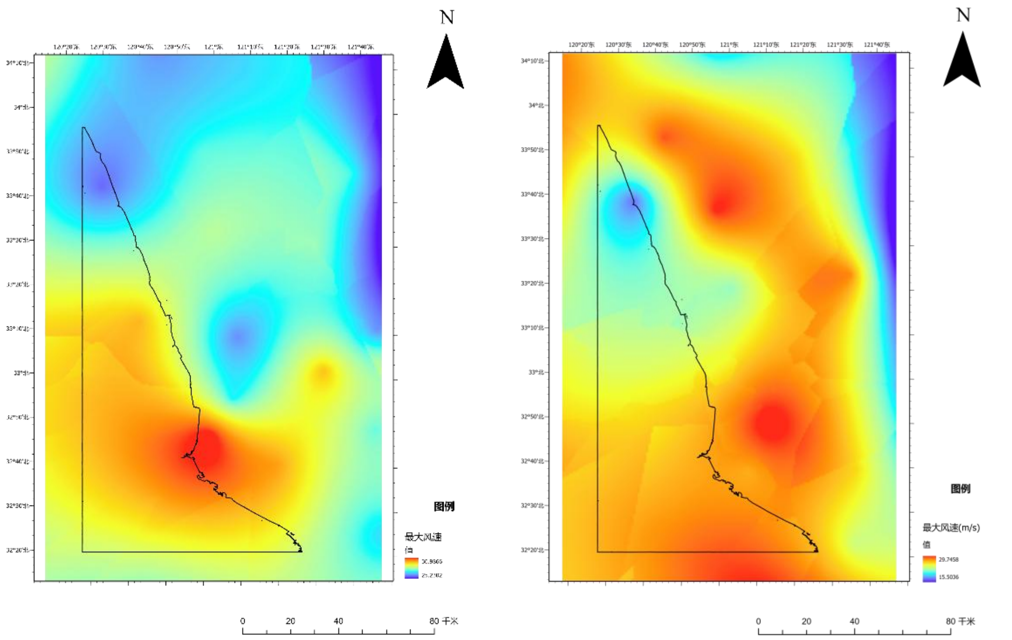

Fig.6 Maximum transit wind speed of Typhoon Rumbia under Holland wind field model (left) Maximum wind speed over Hagupit (right)

Using the Simpson wind damage index method, the wind damage index of the shallow beach in NJP before and after the two typhoon crossings was calculated based on the wind field data, reflecting the intensity of wind damage and the degree of risk posed by the storm surge to the shallow beach in NJP. The principle of the Simpson wind damage index method is to use the factors of wind speed, wind direction, wind duration, and the value of the storm surge surge water increase to establish a comprehensive wind damage index, and to indicate the damage and degree of hazard of the wind damage with a hierarchical system. Equation (4) of the Simpson wind damage index method is as follows:

$$PI = \sum_{i=1}^{n} I_i \qquad (4)$$

where PI is the wind hazard cumulative index; n is the total number of wind speed data for each grid point; and Ii is the wind hazard index corresponding to the wind speed, i = 1, 2, ..., n.

The Simpson Wind Hazard Index (SWHI) is a metric used to assess the risk of wind damage that combines the effects of wind speed and wind duration. It is calculated by adding the wind hazard indices corresponding to the wind speeds at each spatial grid point to obtain a cumulative wind hazard index. The magnitude of the wind hazard index depends on the level of wind speed; the higher the wind speed, the higher the wind hazard index. The magnitude of the wind damage cumulative index reflects the severity of the wind damage; the higher the wind damage cumulative index, the higher the wind damage level.

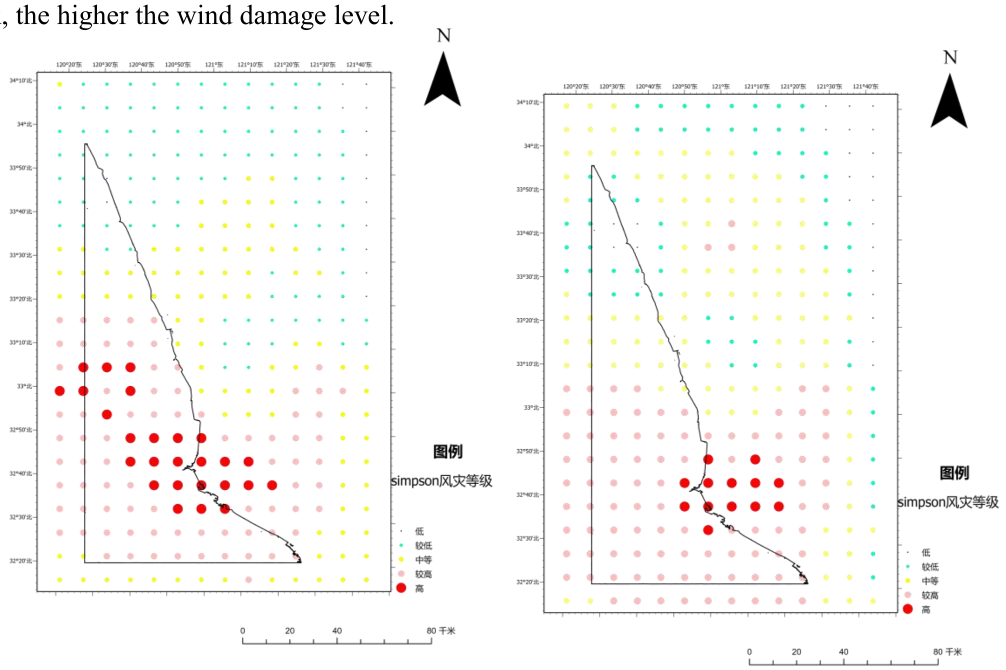

Fig.7 Simpson wind Disaster index in the typhoon Disaster index of Rumbia (left)

Hagupit Transit Disaster Index (right)

The results of the spatial distribution of wind hazard classes in TC from 2017 to 2021 are shown in Figure 6. It can be seen that there are obvious regional differences in the spatial distribution of wind hazard classes. （The wind hazard class in the region of (121° to 121.5°E, 32.3° to 32.8°N) is relatively high, and all wind hazard classes are located at high or higher levels. Other regions have relatively low wind hazard levels.

From south to north, the spatial distribution of the wind hazard level in the offshore and the offshore shows different characteristics, among which the wind hazard level in the offshore increases from south to north, and the wind hazard level increases from the "low" level to the "high" level. The wind hazard index of Yancheng shallow nearshore harbor is higher in Winnebago and Hagupit.

3.3 Hydrodynamic model calculation results and analysis

In order to study the mechanism and effect of hydrodynamics on the topographic change of the shallow bank in North Jiangsu Province, as well as the interaction and influence of hydrodynamics with storm surge, topography and other factors, this paper utilizes the hydrodynamic model, combined with the bathymetry remote sensing data, to simulate the hydrodynamic parameters of the shallow bank in NJP, including the flow field, water level, and sediment transport and transportation. The hydrodynamic parameters are the core data of this paper to study the change of hydrodynamics on the topography of the shallow bank in NJP, and they are also the main data of hydrodynamics with storm surge, topography and other factors.

In this paper, a hydrodynamic model based on the finite element method is selected, which is able to adapt to the complex topography and boundary conditions of the shallow bank in NJP, and at the same time, the bathymetric remote sensing data are utilized for calibration and validation, so as to improve the accuracy and reliability of the hydrodynamic model. The hydrodynamic model of finite element method is a method based on physical process and mathematical model, which can simulate the flow field, water level, sediment transport and other hydrodynamic parameters of the shallow bank in NJP. In this paper, the M21FLOW-FM module is adopted as the hydrodynamic model of this paper. The M21FLOW-FM module is a three-dimensional hydrodynamic model that can simulate non-constant processes such as water flow, water level, salinity, temperature, sediment transport, etc., and at the same time, it takes into account the influence of external driving factors such as wind, tide, wave, river, precipitation, etc. The basic equations of the M21FLOW-FM module are three-dimensional non-constant continuity equation, momentum equation, material transport equation and turbulence equation, which are numerically solved by finite difference method and finite element method with high stability and accuracy.

Using the bathymetric remote sensing data, the boundary conditions and initial conditions of the hydrodynamic model were set, and the input parameters of the hydrodynamic model were obtained; using the M21FLOW-FM module, the hydrodynamic parameters of the shallow bank in

NJP were calculated according to the input parameters of the hydrodynamic model, and the output parameters of the hydrodynamic model were obtained; using the measured water level data and the sediment transport data, the output parameters of the hydrodynamic model were calibrated The output parameters of the hydrodynamic model were calibrated and verified using measured water level data and sediment transport data to assess the accuracy and reliability of the hydrodynamic model, and the final hydrodynamic data were obtained.

3.3.1 Flow field simulation results and analysis

The results of hydrodynamic modeling calculations before and after the transit of two typhoons, Typhoon Wenbya in August 2018 and Typhoon Hagupit in September 2020, are selected as the research objects of this paper. Both typhoons are strong typhoon level storms, which have caused serious impacts on the shallows of NJP. Using a hydrodynamic model, this paper simulates the hydrodynamic parameters before and after the transit of the two typhoons, including the flow field, water level, sediment transport, etc., and analyzes the mechanism and effect of hydrodynamics on the change of topography of the shallow beach in NJP, as well as the interactions and impacts of the hydrodynamics with the storm surges, topography, and other factors.

The flow field is one of the basic output parameters of the hydrodynamic model, which reflects the direction and velocity of the water flow, and is one of the main factors affecting the topographic change of the shallow beach in NJP. In this paper, using the hydrodynamic model, the flow field parameters before and after the crossing of two typhoons are simulated, and the mechanism and effect of the flow field on the topographic change of the shallow shoal in northern Jiangsu are analyzed, as well as the interaction and influence of the flow field with the storm surge, topography and other factors.

The results of the hydrodynamic calculations are shown in Fig. 8, and Fig. 9 When the typhoon transits, the flow field of the NJP shoal is mainly affected by the storm surge, which shows obvious storm surge characteristics, with a larger flow velocity and a more complicated flow direction, and is distributed along the direction of the typhoon's movement. After the passage of the typhoon, the flow field in the NJP shoal had an important influence on the water level changes in the NJP shoal, leading to the abnormal increase and decrease of the water level, as well as the uneven distribution of the water level. After the typhoon's transit, the flow field of the NJP shoal also played an important role in sediment transport in the NJP shoal, leading to sediment erosion, transportation and deposition, thus changing the topography of the NJP shoal.

This paper further compares the differences in hydrodynamic parameters after the two typhoon transits, and finds that there are some similarities between the impacts of Typhoon Winnebago and Typhoon Hagupit on the NJP shoal, but there are also some differences. After the transit of the two typhoons, the maximum water level and the maximum flow velocity of the NJP shoal appeared in the area near Yancheng, and both of them exceeded the historical records, indicating that this area is the most vulnerable area of the NJP shoal to the typhoon. After the two typhoons, the sediment transport in the NJP shoal increased significantly, and both of them showed coastal transport and lateral transport, indicating that these two modes of transport are the main modes of topographic changes in the NJP shoal. After the two typhoons, the topography of the NJP shoal changed significantly, mainly in the form of coastal erosion and sedimentation in the central and southern parts of the shoal, indicating that these two areas are the main areas of topographic change in the NJP shoal. The differences in the hydrodynamic parameters of the northern Suzhou Shoal after the transit of the two typhoons are mainly reflected in the following aspects: the maximum water level and the maximum flow velocity of Typhoon Wenbya are slightly lower than those of Typhoon Hegbi, indicating that Typhoon Hegbi is more intense and has a stronger impact on the NJP shoal. The direction of sediment transport of Typhoon Wenbia was more littoral, whereas that of Typhoon Heigbi was more lateral, indicating that the two typhoons had different impacts on the topographic changes of the NJP Shoal. The topographic changes of Typhoon Winnebago are more oriented to coastal erosion, while the topographic changes of Typhoon Heigbi are more oriented to sedimentation in the central and southern parts of the shoal, indicating that the two typhoons have different impacts on the topographic changes in the northern part of the shoal.

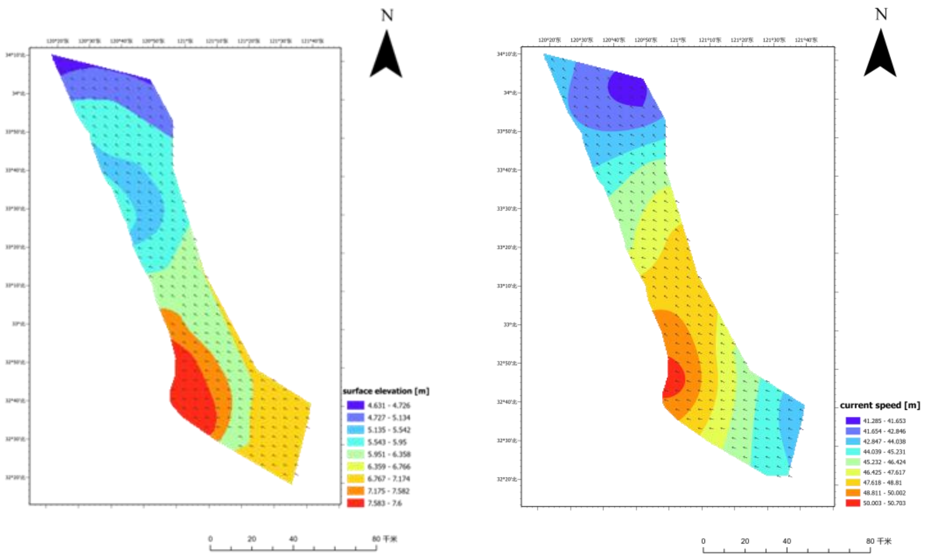

Fig.8 Model of water height and water velocity in transit period of Rumbia

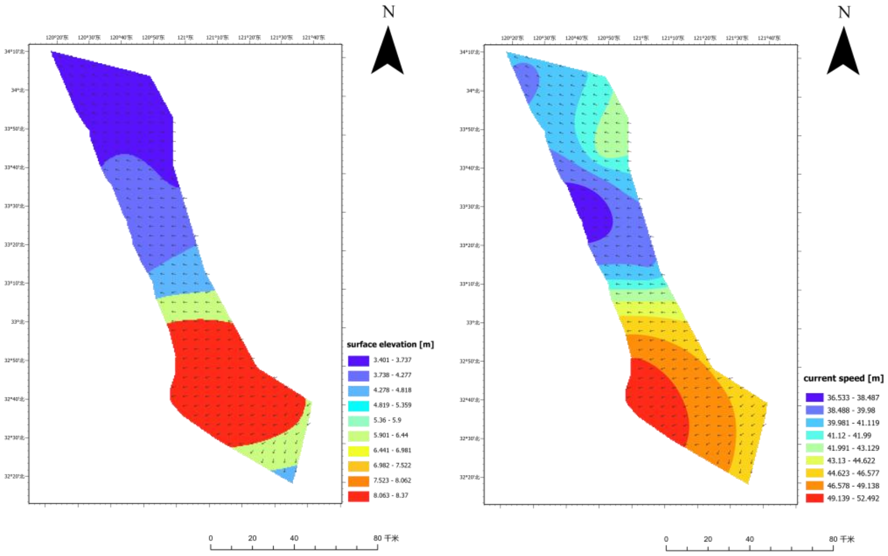

Fig.9 Model of water height and velocity in Hagupit transit period

4 Conclusion

This paper focuses on the topographic changes of the shallow shoal in NJP and its relationship with storm surge, as well as the mechanism and effect of hydrodynamics. A variety of data sources and data processing methods, including satellite remote sensing technology, wind field analysis technology, hydrodynamic model, etc., were used to obtain the bathymetry data, wind field data, wind index data, hydrodynamic data, etc., and analyze the characteristics of the topographic change of the shallow bank in NJP, the influencing factors of the storm surges, and the process of hydrodynamics, etc., and the following main conclusions and innovations were obtained:

(1) Using ICESat-2 and Landsat-8 satellite data, combined with three kinds of semi-empirical functions, the bathymetry data of the shallow beach in NJP were inverted, which provided basic data for the study of topographic change. Using the laser altimeter data from ICESat-2, the seafloor elevation was determined, and then using the spectral data from Landsat-8, the relationship between bathymetry and albedo was fitted, and a bathymetric map was obtained and the bathymetric data were corrected and verified to assess their accuracy and reliability. The main innovation is the utilization of high-precision truth data and diverse fitting functions to improve the accuracy and adaptability of the bathymetric inversion.

(2) Using the TC best path dataset, combined with the Holland wind field analysis method and the Simpson wind damage index method, the wind field data and wind damage index data of the shallow shore of NJP were extracted, which provided key data for the storm surge impact

study. Utilizing the basic information of TC, the wind field parameters and wind hazard index of the storm surge were calculated to reflect the intensity and hazard of the storm surge, and the wind field data and wind hazard index data were calibrated and verified to assess their accuracy and reliability. The main innovations are the utilization of a comprehensive wind field analysis method and wind hazard index method to comprehensively assess the impact of storm surge on the shallow shore of NJP, and the utilization of a wind field parameterization scheme for typhoon winds in the East China Sea, which improves the adaptability and accuracy of the wind field simulation.

(3) The hydrodynamic model of the finite element method was utilized to simulate the hydrodynamic parameters of the NJP shoal in conjunction with the bathymetric remote sensing data, which provided the core data for the study of hydrodynamic effects. In this paper, the hydrodynamic parameters such as flow field, water level, sediment transport, etc. of the shallow bank in NJP are simulated using the M21FLOW-FM module, taking into account the influence of external driving factors such as wind, tides, waves, rivers, precipitation, and so on. In this paper, the boundary conditions and initial conditions of the hydrodynamic model are set using the bathymetric remote sensing data, and the input parameters and output parameters of the hydrodynamic model are obtained. In this paper, the output parameters of the hydrodynamic model are calibrated and verified to assess its accuracy and reliability. The main innovation is that the hydrodynamic model of the finite element method is utilized to simulate the hydrodynamic process in three dimensions of the shallow beach in NJP, and the influence of multiple external driving factors is considered to improve the complexity and realism of the hydrodynamic simulation, and remote sensing data of the water depth are utilized to improve the accuracy and reliability of the hydrodynamic simulation.

The results of this paper are of great significance to the ecological environment and socio-economics of the NJP shoal. Changes in topography will change the hydrological, water quality, biological and other characteristics of the NJP shoal, thus affecting the ecological function and service value of the NJP shoal. The results of this paper can provide scientific basis and reference for the ecological protection and resource development of the NJP shoal, and also provide technical support and guidance for wind hazard risk assessment and disaster prevention and mitigation in the NJP shoal. Although the data sources and data processing methods in this paper are relatively diverse and perfect, there are still some errors and uncertainties, which may affect the accuracy and reliability of the data, and it is hoped that the data sources and data processing methods in this paper will be gradually improved in the future work, so as to make more results.

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