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Numerical simulation of typhoon-induced storm surge along Jiangsu coast, Part I: Analysis of tropical cyclone

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Abstract

The Tropical Cyclone Best Track Dataset issued by the Shanghai Typhoon Institute of the China Meteorological Administration, for the period from 1949 to 2013, was analyzed, and the typhoons threatening the Jiangsu coast were categorized into three different classes in terms of track, including typhoons making straight landfall, typhoons active in offshore areas, and typhoons moving northward after landfall. On the basis of the 65-year dataset, the typhoon parameters of these three categories, including the central pressure and the maximum wind speed, were investigated. Statistical analysis suggested that the minimum central pressure increased northward and shoreward gradually. The relationship between the maximum wind speed and the minimum central pressure was established through second-order polynomial fitting. Considering typhoons No. 1210, No. 0012, and No. 9711 as the basic typhoons, ten hypothetical cyclones with typical tracks and minimum central pressure occurring during the period from 1949 to 2013 were designed, providing the driving conditions for numerical simulation of typhoon-induced storm surges along the Jiangsu coast.

Keywords: Jiangsu coast; Hypothetical tropical cyclone; Central pressure; Maximum wind speed; Typhoon track

1. Introduction

The Jiangsu coast, located on the western side of the South Yellow Sea, is affected by the unique convergence and divergence of the South Yellow Sea amphidromic wave system and the East China Sea forward tidal wave system (Chen et al., 2009; Zhang et al., 2013; Zhou et al., 2015). This stretch of coast includes the abandoned Yellow River delta in the north and the radial sand ridges in the south. Typhoon-induced storm surges are one of the severest types of disasters off the Jiangsu coast, and typhoons destroy offshore facilities and coastal structures as well as ships (Feng et al., 2012). When the wind speed is above 10 on the Beaufort scale, a storm surge that overlaps with a high astronomical tide is defined as a super-large storm tide, and the causes for the super-large storm tides along the Jiangsu coast have been analyzed (Chen, 1991). Lu et al. (2002) analyzed the main patterns of storm surge disasters along the Jiangsu coast and their influence on the coastal economy. Yu et al. (2009) investigated the assessment method of direct and indirect economic losses caused by storm surges along the coast of Yancheng in Jiangsu Province and provided the storm surge bearing loss rate. According to the wind and rain intensities of typhoons affecting Jiangsu Province, the influence is classified into four levels: lightest influence, heavier influence, severe influence, and severest influence levels (Gan, 2006). In terms of track, the typhoons are classified into five categories, which are typhoons moving northward after landfall, typhoons vanishing after landfall, typhoons making straight landfall, typhoons active in offshore

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areas, and typhoons making landfall near the South China Sea and then exiting along the Jiangsu coast (Xiang et al., 2008), of which the first category is further sub-divided into three types. This classification system is over-detailed and unfavorable to the study of typhoon-induced storm surges. At present, the wind and rain intensities in various parts of Jiangsu Province are generally used to determine whether typhoons affect Jiangsu Province or not, leading to more accurate results. However, it is very difficult to acquire the ground wind and rainfall data covering a large area over a long period.

In this study, a method for defining the affected domain was used to conduct statistical analysis of the typhoon process affecting Jiangsu Province. According to the typhoon track, the typhoons affecting Jiangsu Province were classified into three categories. Then, statistical analysis of typhoon parameters was carried out to establish a relationship between the minimum central pressure and the maximum wind speed. Finally, ten hypothetical typhoons along the Jiangsu coast were designed on the basis of historical data during the period from 1949 to 2013.

2. Statistical characteristics

The typhoon information was derived from the Tropical Cyclone Best Track Dataset issued by the Shanghai Typhoon Institute of the China Meteorological Administration (Ying et al., 2014). The diameter of a typhoon, depending on its intensity, usually ranges from 600 km to 1000 km. Therefore, centered at the Jiangsu coast, the affected distance was set to be 450 km. Typhoons entering the domain with longitudes from 116°E to 126°6'E and latitudes from 28°N to 38°N were determined to be the typhoons influencing Jiangsu Province, and the domain is shown as the rectangular area in Fig. 1. The FORTRAN program was used to read the historical typhoon information from the best track dataset. A typhoon that entered the selected domain and was stronger than a tropical storm (TS) according to the Chinese national standard *Intensity Category for Tropical Cyclones* (GB/T 19201–2006) was defined as a typhoon process affecting Jiangsu Province. Of the 2157 typhoons in the western North Pacific Basin that occurred during the period from 1949 to 2013, 202 typhoons affected Jiangsu Province, with an annual average number of 3.2. According to the typhoon track distribution, the typhoons influencing Jiangsu Province can be classified into three categories: typhoons making straight landfall, accounting for 3.96%; typhoons active in offshore areas, which do not make landfall, accounting for 14.36%; and typhoons moving northward after landfall, which make landfall along the Zhejiang and Fujian coasts and then move northward inland and affect Jiangsu Province, accounting for 77.72%. In addition to these three categories, there are some other types of typhoons (accounting for 3.96%) with irregular tracks, which are beyond the scope of the present study.

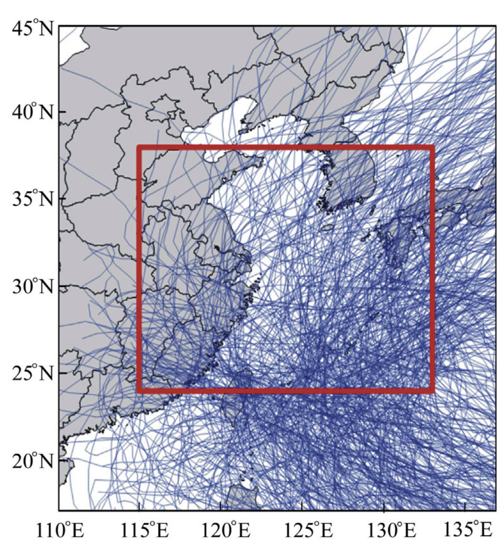

Fig. 1. Tracks of typhoons influencing Jiangsu Province from 1949 to 2013.

3. Parameters of typhoons

Parameters of typhoons include the radius to the maximum wind speed (R_{max}), the forward speed (V_t), the central pressure (p_c), and the ambient pressure (p_n). Based on statistical information from historical typhoons, parallel movement of the real typhoon track was used to obtain the typhoon track and forward speed. The pressure value at one place was taken as the minimum value of the central pressures of typhoons that have occurred over the 65-year period at that place. Then, the relationship between pressure and wind speed was established in order to obtain the wind speed of hypothetical typhoons.

3.1. Central pressure

It was found that in the minimum central pressure distribution there existed a latitude boundary of about 27°N corresponding to 920 hPa. The minimum central pressure was less than 920 hPa, down to 885 hPa to 896 hPa, in the area south of 27°N, while it was larger than 920 hPa and increased with latitude in the area north of 27°N (Duan et al., 2004). Jiangsu Province is located in the mid-latitude area and latitude has a significant influence on the pressure distribution of typhoons (Vickery et al., 2000; Willoughby et al., 2006). Therefore, in order to obtain the information for the central pressure of typhoons in Jiangsu Province, it is necessary to understand the distribution pattern of the minimum central pressure.

The rectangular domain with longitudes from 115°E to 133°E and latitudes from 24°N to 38°N was the study area, covering the North Yellow Sea, the East China Sea, Jiangsu Province, Zhejiang Province, and Fujian Province. The best track dataset from 1949 to 2013 was analyzed, providing a total of 431 typhoons that entered the domain and had an intensity equal to or larger than a grade IV typhoon (TY) according to the Chinese national standard *Intensity Category for Tropical Cyclones* (GB/T 19201–2006). In order to investigate the distribution pattern of the minimum central pressure, the grid cell for the selected domain was 0.5° × 0.5°, and a domain with latitudes from −0.5°N to 0.5°N and longitudes from −0.5°E to 0.5°E from each grid point was the value range of that grid point. The lowest value