Vietnam Journal of Marine Science and Technology; Vol. 19, No. 3; 2019: 327–336
DOI: https://doi.org/10.15625/1859-3097/19/3/13899
https://www.vjs.ac.vn/index.php/jmst

The risk of typhoon and storm surge along the coast of Vietnam

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Received: 20 April 2019; Accepted: 16 June 2019

Abstract
The history (1951–2016) and the risk of typhoon and storm surge in coastal areas of Vietnam are analyzed and evaluated based on the observation data, results of statistical and numerical models. The Monte Carlo method was used to construct a bogus typhoon. A coupled numerical model of Surge, Wave and Tide (called SuWAT) was used for simulation of storm surge. The results show that in the period of 1951–2016 there were many typhoons which landed and induced high storm surge on the coast of the North and the North of Center of Vietnam. During one thousand years, there have been 4,678 typhoons entering the coastal zone from Quang Ninh to Ca Mau. In particular, the most severe typhoon in coastal area from Quang Ninh to Thanh Hoa is at level 16 (Beaufort scale), Nghe An - Quang Tri at level 16, Quang Binh - Phu Yen at level 17, Binh Dinh - Ninh Thuan at level 15 and Binh Thuan - Ca Mau at level 13. The coastal areas with highly vulnerable storm surge are provinces from Quang Ninh to Hai Phong (4.5 m), Thanh Hoa to Nghe An (4.0 m), Quang Tri (5.0 m). The results of this study are the basis for the preparation to cope with strong/super typhoon in the coast of Vietnam.

Keywords: Typhoon, storm surge, Monte Carlo, SuWAT.

Citation: Nguyen Ba Thuy, 2019. The risk of typhoon and storm surge along the coast of Vietnam. *Vietnam Journal of Marine Science and Technology*, *19*(3), 327–336.

INTRODUCTIONS

Typhoon is a dangerous hydro-meteorological disaster whose consequences are coastal inundation, erosion and saltwater intrusion caused by storm surge in combination with high tide and wave. Especially in the context of climate change, it is stated that there will be many strong/super typhoons which could influence the mainland of Vietnam. The world has witnessed several strong typhoons causing flooding in coastal areas on a large scale, resulting in human and property damage, including hurricane Katrina in New Orleans state (the US) in August 2005, and typhoon Nargis in Myanmar in May 2008 and especially the recent typhoon Haiyan with level 17 across the Philippines in November 2013 causing severe damage mainly due to storm-surge-induced inundation. The coastal areas of Vietnam have also recorded typhoons that cause strong winds, high waves and high storm surge such as typhoons Dan (1989), Becky (1999), Damrey (2005), Xangsane (2006), Ketsana (2009) (Chien, 2016).

Study on typhoon and storm surge has been conducted for a long time, mainly focusing on numerical model for operational forecasting. The risk assessment of storm surge due to the impact of climate change currently attract the interest in some countries such as Japan and South Korea, which suffer damages from typhoon and storm surge. Accordingly, storm surge is calculated by synthetic typhoon data from the global storm statistics model, previously verified with historical storm data [1]. These results provide elementary information on planning and designing coastal facilities and mitigations. On the other hand, in the developed countries such as the United States, Canada, Australia, the European Union, Japan, and Taiwan the risk assessment of natural disasters including typhoon and storm surge has been studied to develop response strategies. In the United States, scientists have used simulation data of 2,000 years of typhoons from 100 year historical typhoon data as input to the storm surge model and constructed a storm surge frequency curve for repeated cycles from 2 to 100 years [2]. In Vietnam, Manh et al., (2010) has constructed a set of data on tides, storm surge and total water levels (tide+storm surge) along the coast from Quang Ninh to Quang Nam. In particular, the statistical set of storms is established by the Monte Carlo method based on the probability distribution of the typhoon parameters occurring in the past. In this way, Uu et al., (2009) [3] have combined statistical methods and numerical models to calculate and analyze extreme storm surge with respect to sea level rise due to impacts of climate change in the coastal areas and islands of Vietnam. Most recently, Chien (2016) [4] calculated the risk of storm surge from the coastal area from Quang Binh to Quang Nam based on the bogus typhoon data for 1,000 years, which is determined by the Monte Carlo method.

In order to have a scientific basis for the preparation to deal with strong/super typhoon affecting Vietnam, the government has recently asked the hydro-meteorological sector to study the risk of typhoon and storm surge for each coastal zone of Vietnam. In this study, typhoon and storm surge, which occurred during the period of 1951–2016, as well as the possibility of super/strong typhoon and storm surge in the coastal areas of Vietnam were analyzed. In addition to historical typhoon data for the period 1951–2016, a set of bogus typhoons in 1,000 years has been constructed using the Monte Carlo method. A coupled numerical model of Surge, Wave and Tide is used to simulate storm surge in historical and bogus typhoons.

STUDY AREAS AND METHODS

Study areas

The study area is the coastal area from Quang Ninh to Ca Mau. Due to the change in geographic location, climate, terrain and tides, the frequency, duration and intensity of typhoon and storm surge are various. The history and risk of typhoon and storm surge are analyzed for each coastal area of Vietnam.

Research methods

Statistical methods are used to analyze storm characteristics in each region. Meanwhile, the Monte Carlo method is used to determine the possibility of occurrence of super/strong typhoon in each area and used as input data for storm surge simulation. Based on the Monte Carlo method, a set of bogus typhoons for 1,000 years has been constructed. The theoretical basis of the Monte Carlo method is based on the probability distribution of the historical typhoon parameters to build a set of bogus typhoons for many years [2–4]. The typhoon data in the period from 1951 to 2016 were collected at the National Center for Hydro-meteorological Forecasting and from the website of the Japan Meteorological Agency. Storm surge was calculated by SuWAT model. The theoretical basis and calibration of the SuWAT model in the study area was presented in detail in the works of Kim et al., (2010) [5], Chien (2016) [4], Thuy et al., (2017) [6]. In this study, the SuWAT model was designed on rectangular grids and three domains to simulate storm surge. Information about the domains and grids is shown in table 1.

Table 1. Information of computational domains

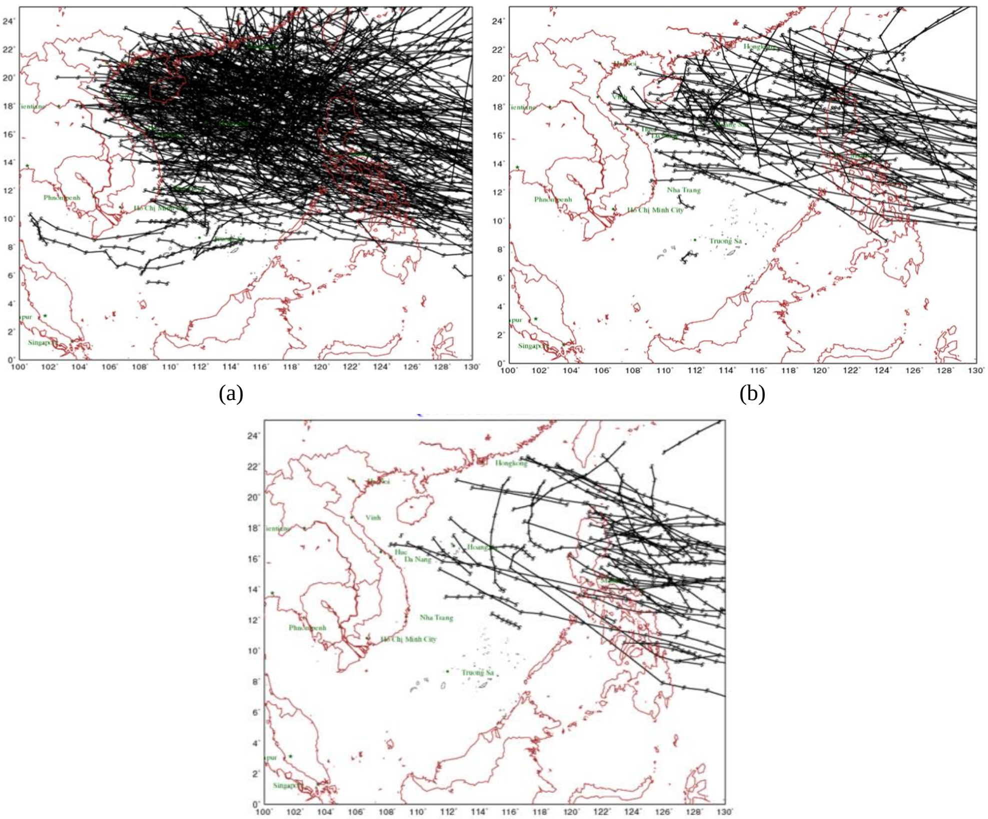
Area	Domain number	Computational Domain	Num.Grid (m)	Grid Size
North of Vietnam	D1	103–120°E, 6–22°N	226 × 211	7,400 × 7,400
	D2	105–110.5°E, 16–21.5°N	181 × 241	1,850 × 1,850
	D3	106–107.5°E, 20.0–21.0°N (for typhoon hitting Hai Phong)	181 × 121	925 × 925
Center of Vietnam	D1	103–120°E, 6–22°N	226 × 211	7,400 × 7,400
	D2	106–111°E, 12.0–18.5°N	301 × 361	1,850 × 1,850
	D3	107.5–109°E, 15.5–16.5°N (for typhoon hitting Da Nang)	181 × 121	925 × 925
South of Vietnam	D1	103–120°E, 6–22°N	226 × 211	7,400 × 7,400
	D2	105–110°E, 8.0–13.0°N	301 × 301	1,850 × 1,850
	D3	106.3–107.6°E, 9.7–10.7°N (for typhoon hitting Vung Tau)	157 × 121	925 × 925

For the simulation of storm surge, the wind and pressure fields were calculated from empirical typhoon model [7]. According to previous study [6] tides only have a significant effect on storm surge when typhoon landfall occurs during spring tides. Meanwhile, storm waves caused most significant effects on storm surge in strong/supper typhoon. As a consequence, the results of storm surge for all historical typhoons take into account the effect of tide, surge and wave. For the case of bogus typhoons, the effect of tide was not considered due to unknown landfall time.

HISTORY AND THE RISK OF TYPHOON AND STORM SURGE IN COASTAL AREAS FROM QUANG NINH TO CA MAU

History of typhoon and storm surge in coastal areas from Quang Ninh to Ca Mau

The present status of typhoon and storm surge is understood as typhoon and storm surge that have occurred in the area. In order to assess the present status of typhoon affecting the coastal areas from Quang Ninh to Ca Mau, the typhoon data in the period of 1951–2016 were analyzed by location of landfall and intensity for each area. To assess storm surge in the area, not only typhoons with eyes across area but also those with eyes outside the area, which are likely to cause significant storm surge in the area are included. Table 2 shows the number of typhoons affecting areas in the East Sea and in Vietnam coast during the period of 1951–2016. Accordingly, the number of typhoons tends to decrease from North to South. The coastal areas from Quang Ninh to Ha Tinh experienced the highest number of typhoons with 342 times, including two typhoons at level 13. The area from Quang Binh to Quang Nam witnessed the highest number of typhoons at level 12–13. The coastal provinces from Vung Tau to Ca Mau showed the least number of typhoons, with only two typhoons at level 12–13. The distribution of typhoon by level in the East Sea and in Vietnam is shown in fig. 1. Statistical analysis shows that during the first half of the typhoon season, the typhoon directions tend to be Northwest, North and Northeast, and have a landfall in the Southeast China. In the rest of the typhoon season, it tends to go to West of Vietnam. On average, from January to May, typhoons are less likely to affect Vietnam. From June to August, typhoons are more likely to affect the North. From September to November, typhoons are more likely to affect the Center and South of Vietnam. In the first half of the typhoon season, the track of typhoon is less complicated; however, the track of typhoon is often more complicated in the second half of the typhoon season.



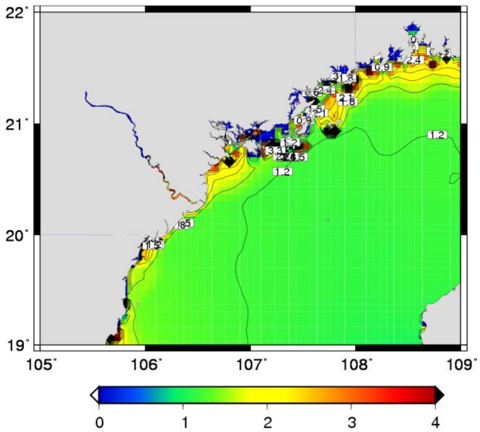
(a) (b)

(c)

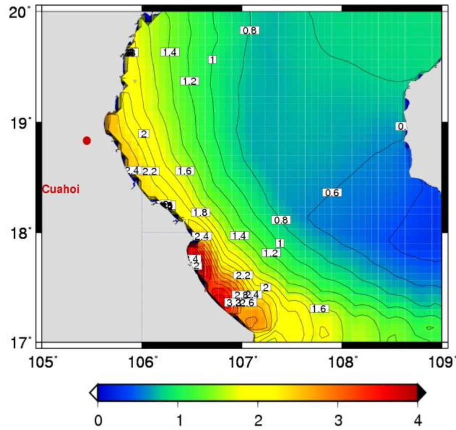
Fig. 1. The track of typhoons in the East Sea of Vietnam: (a) Level 8–11, (b) Level 12–13, (c) Level 13 and higher

Table 2. The number of typhoons affecting areas of the East Sea and coastal area of Vietnam in the period of 1951–2016

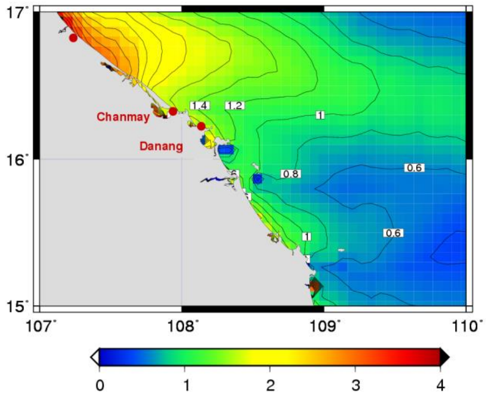
Areas	Level 8–11	Level 12–13	≥ Level 13
Quang Ninh - Ha Tinh	317	23	2
Quang Binh - Phu Yen	307	55	11
Khanh Hoa - Binh Thuan	94	12	1
Vung Tau - Ca Mau	46	2	0
North East Sea	1,816	339	90
Central East Sea	747	97	41
South East Sea	144	6	0
Total	3,471	534	145



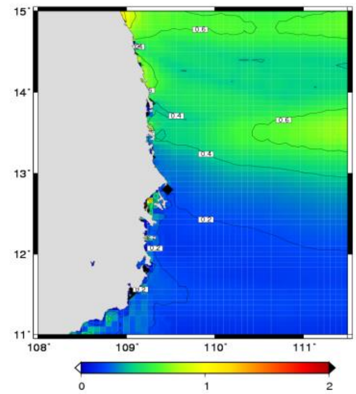
(a) Quang Ninh - Thanh Hoa



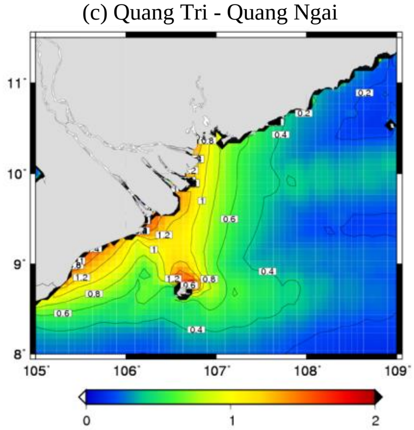
(b) Nghe An - Quang Binh



(c) Quang Tri - Quang Ngai



(d) Binh Dinh - Ninh Thuan



(e) Binh Thuan - Ca Mau

Fig. 2. Distribution of maximum storm surge in the period of 1951–2016

Due to the lack of storm observation data, the way using the numerical model with high reliability is most suitable for assessment of storm surge in the area. Fig. 2 shows the distribution of largest storm surge in coastal areas during 1951–2016, and it is divided into 5 regions: Quang Ninh - Thanh Hoa (a), Nghe An - Quang Binh (b), Quang Tri - Quang Ngai (c), Binh Dinh - Ninh Thuan (d), Binh Thuan - Ca Mau (e). This is the highest storm surge determined by the numerical model for all typhoons entering Vietnam’s coast in the period of 1951–2016. Accordingly, in coastal areas from Quang Ninh to Thanh Hoa, storm with height of 3.0 m has appeared in some provinces such as Quang Ninh, Hai Phong, Thai Binh and Nam Dinh. Most of these areas experienced a storm surge of 2.0 m in height. Some of the typhoons in the area causing high storm surge include Frankie (1996), Damrey (2005) and Kalmaegy (2014). In the coastal zone from Nghe An to Quang Binh, many typhoons have caused high storm surge such as DAN (1989) landing in Ha Tinh, Becky (1990) landing in Nghe An, Harriet (1971) landing in Quang Tri. In which, although typhoon Harriet had a landfall in Quang Tri, it caused a sea level rise over 2.0 m in some areas in Southern Quang Binh. The South of this area saw higher storm surge than in the North, the highest up to 4.0 m. In the coastal zone from Quang Tri to Quang Ngai, the height of storm surge decreases from the North to the South with the decline in frequency and intensity of typhoon in the area. In the north coast, there are many strong typhoons hitting the coast causing high storm surge such as typhoons Harriet (1971), Cecil (1985), Betty (8/1987), Xangsane (September 2006), Ketsana (September 2009) causing a rise of over 2.0 m. In which typhoon Harriet (7/1971) caused a storm surge over 4 m in Quang Tri. In coastal areas from Quang Ngai to Ninh Thuan, storm surge also tends to decrease in level from North to South. The storm surge up to 1.0 m is mainly located in the north of the area. The storm surge in this area is low due to two reasons: Firstly, this is the area with few strong typhoons, although in fact a strong typhoon landed in this area but its direction is not favorable to cause high storm surge (typhoon Durian, 2006 moved obliquely to the shoreline); secondly, its deep sea and steep bed slope reduce the increase of storm surge. The coastal area from Binh Thuan to Ca Mau is very little impacted by typhoon, however, recent storm surge up to 1.5 m (in Ghenh Hao) during typhoon Linda (1997) was recorded. The number of strong typhoons is small, but this area has shallow water depth, therefore many places in this area have faced the surge of 2.0 m.

The risk of typhoon and storm surge form Quang Ninh to Ca Mau

Based on the probability distribution functions of the obtained historical typhoon parameters, a set of bogus typhoons for 1,000 years has been constructed, including 6,213 typhoons, in which 4,678 typhoons hit the coast of Vietnam from Quang Ninh to Ca Mau. The average number of typhoons entering the Quang Ninh - Ha Tinh waters is 2.35 per year; the waters of Quang Binh - Phu Yen have experienced 1.48 typhoons/year; and those from Khanh Hoa to Binh Thuan and from Vung Tau to Ca Mau are 0.50 and 0.36, respectively.

Table 3. Statistics of typhoons for 1,000 years by Beaufort scale (the number of typhoon/percentage) in four areas from Quang Ninh to Ca Mau

Beaufort scale	Study Areas			
	Quang Ninh - Ha Tinh	Quang Binh - Phu Yen	Khanh Hoa - Binh Thuan	Vung Tau - Ca Mau
Tropical depression	663/14.17%	413/8.83%	139/2.97%	105/2.24%
8	483/10.32%	330/ 7.05%	105/ 2.97%	72/1.54%
9	505/10.80%	310/ 7.05%	112/ 2.39%	78/1.67%
10	196/ 4.19%	122/ 2.61%	38 / 0.81%	28/0.60%
11	144/ 3.08%	100/ 2.14%	24/ 0.51%	29/0.62%
12	316/ 6.76%	183/ 3.91%	74/ 1.58%	44/0.94%
13	18/ 0.38%	10/ 3.91%	1/ 0.02%	6/0.13%
14	8/ 0.17%	7 / 0.15%	2/ 0.04%	
15	6/ 0.13%	2/ 0.04%	2/ 0.04%	
16	1/ 0.07%	1/ 0.02%		
17		1/ 0.02%		
Total	**2340/50.02**	**1479/31.62**	**467/10.62**	**362/7.74%**

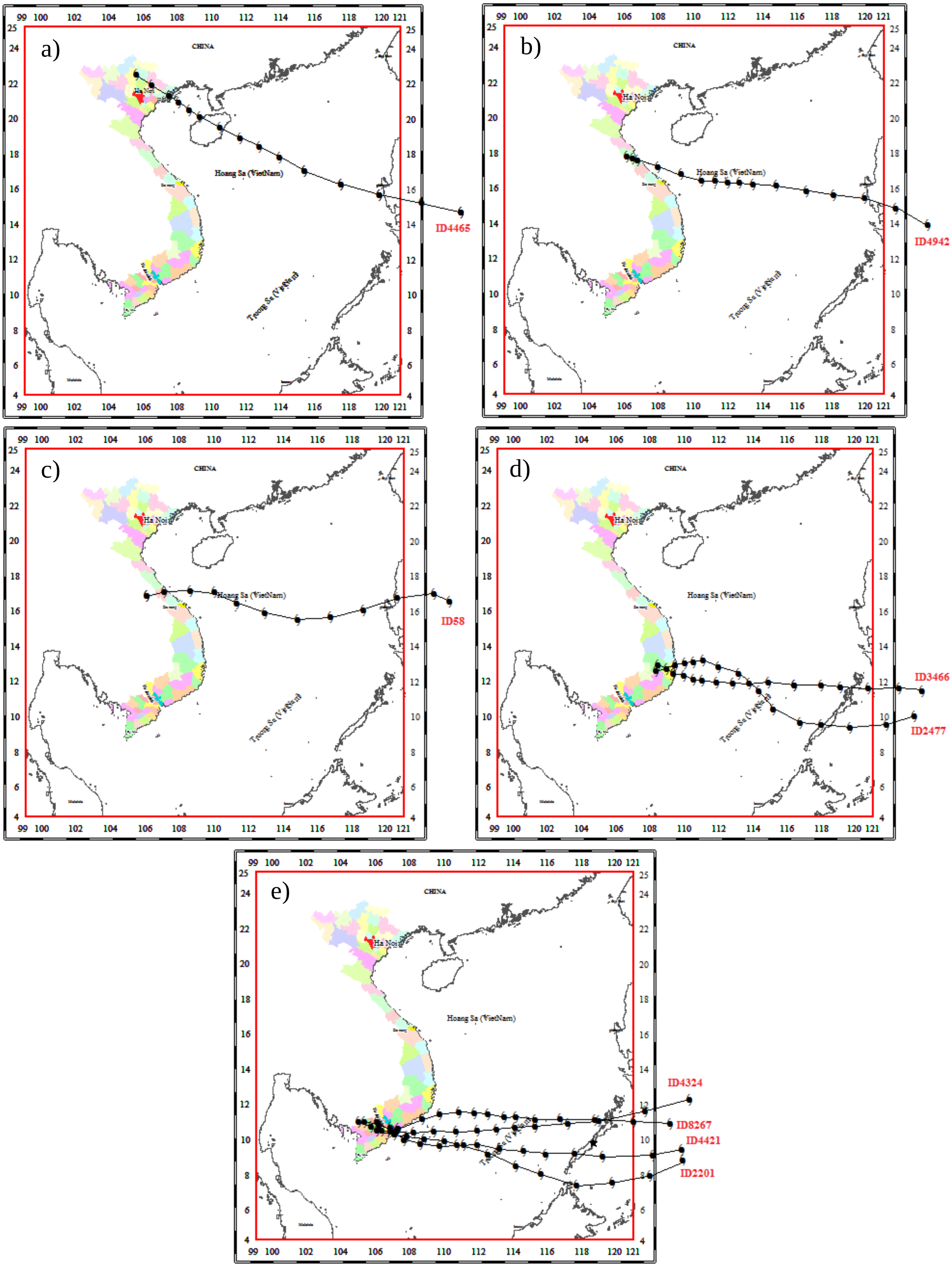


Fig. 3. The track of bogus typhoon landfall at: Level 16 of Quang Ninh (a), level 15 of Quang Binh (b), level 17 of Quang Tri (c), level 15 of Phu Yen - Khanh Hoa (d) and level 12 of Binh Thuan -Vung Tau (e)

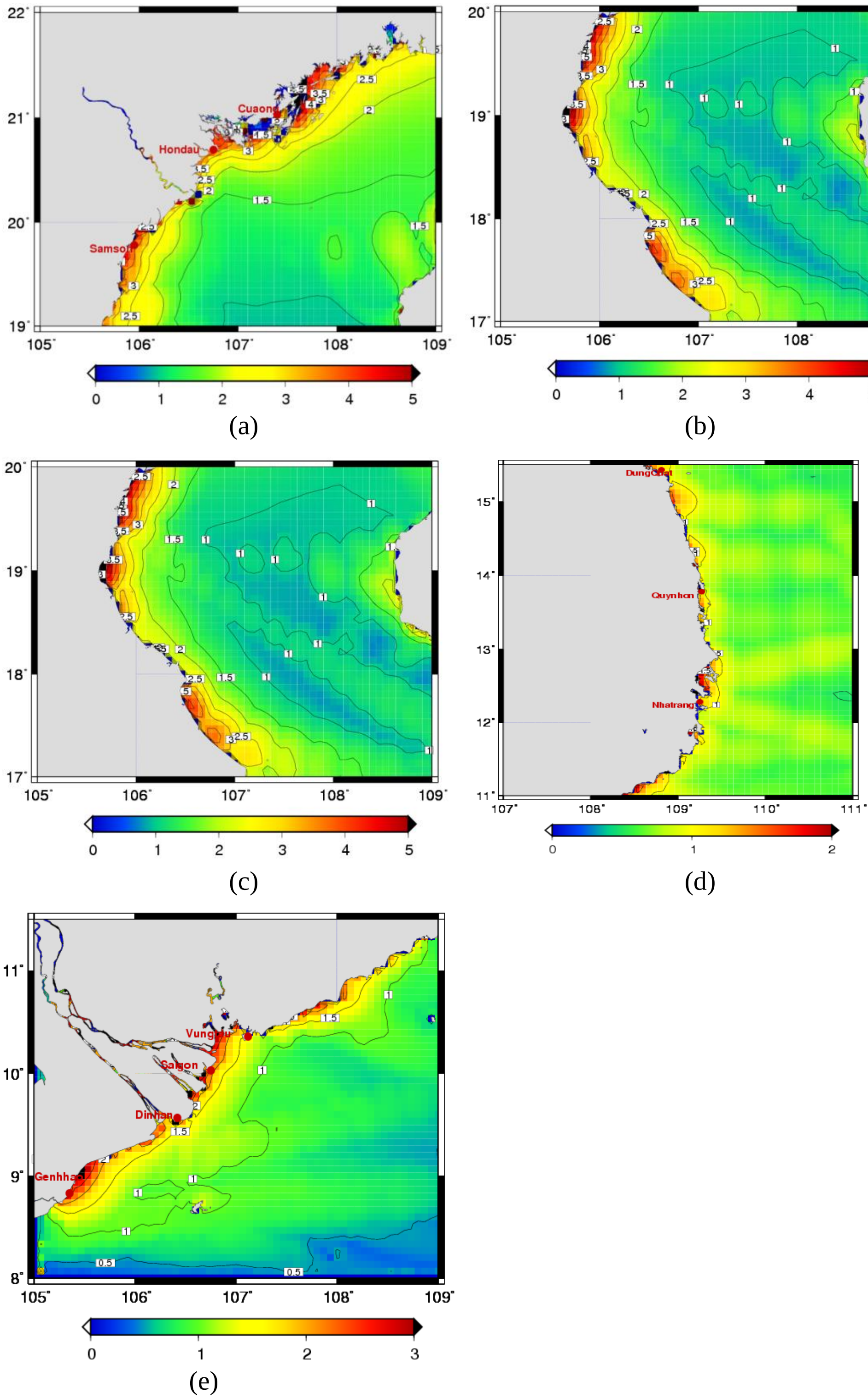


Fig. 4. The distribution of highest storm surge in areas according to the bogus typhoon data: (a) Quang Ninh - Thanh Hoa, (b) Nghe An - Quang Binh, (c) Quang Tri - Quang Ngai, (d) Binh Dinh - Ninh Thuan and (e) Binh Thuan - Ca Mau

The statistical results of the number of typhoons by Beaufort scale in four areas: Quang Ninh - Ha Tinh; Quang Binh - Phu Yen; Khanh Hoa - Binh Thuan and Vung Tau - Ca Mau are shown in table 3. Accordingly, the number of tropical cyclones is in parentheses, while the next one is the corresponding percentage in each area compared to the whole coast of Vietnam from Quang Ninh to Ca Mau. The results showed that in Quang Ninh - Ha Tinh strongest typhoon at level 16 could occur, particularly coastal areas from Quang Binh to Phu Yen could have typhoon at level 17, the Khanh Hoa - Binh Thuan waters could have typhoon at level 15, and from Vung Tau to Ca Mau the strongest typhoon appeared at level 13. Fig. 3 shows the orbits of some strongest typhoons hitting the areas.

Based on the statistical summation of typhoons in the 1,000 years, the risk of storm surge is calculated for all typhoons hitting each area. Fig. 4 shows the distribution of maximum storm surge in the coastal areas of Quang Ninh - Thanh Hoa (a), Nghe An - Quang Binh (b), Quang Tri - Quang Ngai (c), Binh Dinh - Ninh Thuan (d) and Binh Thuan - Ca Mau (e). The results show that for each coastal area, the storm surge does not follow a common trend from North to South. The maximum storm surge depends not only on typhoon parameters (intensity and direction), but also on the terrain (water depth, slope and shape of the coast line). The areas with shallow water and gentle slope often have higher storm surge. The whole coastal zone from Quang Ninh - Thanh Hoa is at the risk of surge over 3.0 m. Due to the high number of strong typhoons concentrated in Quang Ninh, Hai Phong and Thanh Hoa, these areas are at higher risk of storm surge. The highest storm surge may occur in Quang Ninh and Hai Phong at 4.5 m, and in Thanh Hoa at 4.0 m. The coastal area of Nghe An, North of Ha Tinh and Quang Binh have faced storm surge at 4.0 m. In the coastal zone from Quang Tri to Quang Ngai the areas with high storm surge are Quang Tri, Hue and Da Nang bay. In the southern part of Da Nang, Quang Nam and Quang Ngai, the storm surge is smaller. The storm surge in Quang Tri reaches the highest level at 5.0 m. In the coastal zone from Binh Dinh - Ninh Thuan, although present typhoon at level 15 hit Khanh Hoa, storm surge is not high (above 2.0 m) because this is deep water area. In the coastal area of Southern Vietnam (Binh Thuan - Ca Mau), except for Ca Mau, the other areas are at risk of storm surge up to 2.0 m. In which, the risk of highest surge up to 2.5 m is concentrated in the coastal areas of Vung Tau, Tien Giang and Bac Lieu.

The assessment of current status and risk of typhoon and storm surge in Vietnam’s coastal zone will serve as basis for the preparation to cope with typhoon and storm surge in Vietnam.

CONCLUSIONS

In this study, the history and risk of typhoon and storm surge in coastal areas from Quang Ninh to Ca Mau were analyzed based on observation data, statistical and numerical modeling results. In addition to the typhoon data in the period of 1951–2016, a set of bogus typhoons for 1,000 years has been constructed by using the Monte Carlo method to obtain enough data to assess the risk of typhoon and storm surge. The results can be summarized as follows:

The number of typhoon tends to decrease from North to South. In the period 1951–2016, the coastal area from Quang Ninh - Ha Tinh experienced the highest number with 342 typhoons, including two strongest typhoon of level 13. The area of Quang Binh - Quang Nam has recorded the strongest typhoons, at level 12–13. The coastal area from Vung Tau - Ca Mau had the least number of typhoons, with strongest ones at level 12–13. The coastal provinces from Quang Ninh to Thanh Hoa experienced storm surge up to 3.0 m. In the South area of Nghe An - Quang Binh and the North of Quang Tri to Quang Ngai, storm surge can reach over 4.0 m. Binh Thuan - Ca Mau also recorded storm surge up to 1.5 m.

In the 1,000 years there were 6,213 typhoons, in which 4,678 typhoons hit the coastal region from Quang Ninh to Ca Mau, in particular Quang Ninh - Thanh Hoa at level 16, Nghe An - Quang Tri at level 16, Quang Binh - Phu Yen at level 17, Binh Dinh - Ninh Thuan at level 15 and Binh Thuan - Ca Mau at level 13.

The risk of storm surge in the 1,000 year period shows that the trend of storm surge is not quite geographical and the areas with high storm surge are Quang Ninh - Hai Phong (4.5 m), Thanh Hoa - Nghe An (4.0 m), Quang Tri (5.0 m). The coastal area of southern part is also at risk of storm surge up to 2.5 m.

Acknowledgments: This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.06-2017.07, which the authors gratefully acknowledge.

REFERENCES

[1] Yasuda, T., Nakajo, S., Kim, S., Mase, H., Mori, N., and Horsburgh, K., 2014. Evaluation of future storm surge risk in East Asia based on state-of-the-art climate change projection. *Coastal Engineering*, *83*, 65-71.

[2] Manh, D. V., et al., 2010. Sea level calculations for the design of coastal works. *Publishing House for Science and Technology, Hanoi.*

[3] Uu, D. V., et al., 2010. Assessment of extreme sea level changes due to the effects of climate change for the marine economic strategy. *Final Report KC-09.23/06–10, Hanoi*.

[4] Chien, D. D., 2016. Research on calculating and assessing the magnitude of storm surge in the sea from Quang Binh to Quang Nam. *Doctoral Thesis of Oceanography, Hanoi University of Sciences, Vietnam National University*.

[5] Kim, S. Y., Yasuda, T., and Mase, H., 2010. Wave set-up in the storm surge along open coasts during Typhoon Anita. *Coastal Engineering*, *57*(7), 631–642.

[6] Thuy, N. B., Kim, S., Chien, D. D., Dang, V. H., Cuong, H. D., Wettre, C., and Hole, L. R., 2016. Assessment of storm surge along the coast of central vietnam. *Journal of Coastal Research*, *33*(3), 518–530.

[7] Fujita, T., 1952. Pressure distribution within typhoon. *Geophysical Magazine*, *23*, 437–451.

[8] http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html.