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Activity of Typhoons in the Spratly Archipelago (the South China Sea)

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Abstract: On the basis of statistical analysis, studies of the features of the distribution of typhoons in the Spratly Archipelago (the South China Sea) for the period 1884–2020 were carried out using satellite information. As a result, it was revealed that 229 typhoons were observed over the water area of the Spratly Islands during this period. Of these, 27 had a maximum speed of over 33 m/s. A clear trend is identified towards an increasing number of typhoons, which could be a major source of regional climate risks in the future. This is probably due to the intense development of the East Asian Monsoon with a strong tropical convergence zone under current climatic conditions.

Keywords: South China Sea, Spratly Archipelago, tropical cyclones, typhoons

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Introduction

At present, in the context of the formation of a multipolar international system and the shift of the center of power to the Asia-Pacific region (APR), contradictions between states in maritime foci of instability are becoming more acute. The South China Sea (SCS) is one of such hotspots in the Asia–Pacific region, where the interests of many countries collide [*Vasiliev and Shavlay*, 2020].

The Spratly Archipelago is located in the southeastern part of the SCS (Figure 1). The name "Spratly" (the full name is "Spratly Sand Islands") was given in 1843 by Captain Richard Spratly [*Hancox and Prescott*, 1995]. It occupies the territory of 6°50'–12° N and 111°30'–117°20' E. The total area of the region is more than 400 thousand km^2, its center is located 400 km from the islands of Palawan and Borneo, 500 km from the coast of Vietnam, and 1000 km from of the Hainan Island (China).

The archipelago consists of more than 100 small islands, reefs, and atolls with a total area of less than 5 km^2. Two islands (Spratly Island and Southwest Cay Island) in this archipelago, which represent the northern and southern regions of the Spratly Islands waters (Figure 1, Figure 2) [*Le et al.*, 2015]. Vietnamese meteorological stations are located on these islands, where regular observations of meteorological parameters are conducted by scientists at Southern Regional Hydrometeorological Centre, belong to National Centre for Hydro-Meteorological Forecasting (NCHMF) under the Ministry of Natural Resources and Environment of Vietnam (https://en.monre.gov.vn/). A brief description of these islands is given below.

Spratly Island is an atoll in the Spratly Islands Cluster, which is the fourth-largest island in the archipelago (Figure 2a). The length of the island is 1300 meters and its width is 500 meters.

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Figure 1. Spratly Islands Map [*Wikipedia*, 2024a].

Southwest Cay Island – Southwest Reef at the northwestern tip of the Spratly Islands in the SCS (Figure 2b). It is part of the North Danger Reef Atoll, located just 1.75 nautical miles southwest of the Northeast Reef. It is the sixth largest among the Spratly Islands.

The study of the hydrometeorological conditions of the Spratly Archipelago is very important because it influences the climate of the entire SCS. The general feature of the climate of the study area is its tropical monsoon climate-northeast and southwest monsoons, and characterized by storms. From February to May is the dry season, and from May to January the following year is the rainy season.

The first surveys and scientific research in the Spratly Archipelago were conducted on Nam Yet Island at the end of the 19th century. Marine research in the Spratly Archipelago began in 1924 after the French founded the Indochina Institute of Oceanography in Nha Trang (1922).

This institute was headed by the French government, which used the ship De Lanessan (launched in 1924) for scientific research. A French expedition first took place on the above

Figure 2. Satellite images: a – the Spratly Island [*Wikipedia*, 2024b], b – the Southwest Cay Island [*CSIS*, 2024].

ship to the Spratly archipelago in July 1927. Then the Institute of Oceanography of Indochina made expeditions until 1939. The main investigations of the period 1927–1939 focused on geology, hydrology, biology, and tidal conditions [*Chevey and Carton*, 1934; *Institut Océanographique de L'Indochine*, 1931; *Krempf*, 1927; *Robson*, 1928].

The advances in understanding SCS oceanography have been reviewed in the middle of the 20th century with the works of the American scientists [*Dale*, 1956; *Wyrtki*, 1961].

The most outstanding studies of SCS oceanography were the joint NAGA program (1959–1961) with participation of the USA, Vietnam and Thailand, and the US Navy program (1965–1966). Expeditions under these programs obtained a lot of meteorological, hydrodynamic, geological, biological, and acoustic data in the SCS, including the Spratly area [*Wyrtki*, 1961].

One of the first investigations of tropical cyclones (TC) hazards over the SCS was the work of McGregor [*McGregor*, 1995] for the period 1970–1989. Analysis reveals that the inter-annual variations in the areal extent and spatial dispersion of tropical cyclone activity can be used as an index of tropical cyclone hazard potential in the South China Sea. Implications for the general assessment of the tropical cyclone hazard potential in the South China Sea are discussed.

The paper [*Hang et al.*, 2010] used TC data from 1945 to 2007 within the coastal waters of Vietnam. Results were obtained indicating an increasing trend in the number of TCs and more TC activity during La Niña than during El Niño. The paper [*Uu*, 2011] used tropical cyclone data from 1959 to 2010. The result showed that almost all TCs made landfall in North Vietnam. It was concluded that there was a decrease in the number of TCs in the 1980s. This is probably due to the Pacific Decadal Oscillation. In the article [*Duy et al.*, 2016] TCs for the period 1978–2015 were analyzed. The result showed that 59% of tropical cyclones retained their intensity when moving from the Pacific to the SCS. This figure is 25% for typhoons. The Paracel Islands region is directly affected by an average of 11–12 TCs per year, while the Spratly Islands region is directly affected by 5–6 TCs per year.

Joint Vietnamese-Soviet oceanographic research (Institute of Marine Research of the SRV – Far Eastern Scientific Center of the USSR Academy of Sciences) in the SCS was conducted under the SCS project from 1979 to 1995 on Soviet vessels. Many joint papers were published and PhD thesis were defended. But all these works were carried out on the shelf of Vietnam, and in passing touched the Spratly Archipelago.

Vietnamese scientists conducted research in the Spratly Islands within the framework of the national project "48B" in 1986, 1988, 1989–1998. A collection of scientific articles on natural conditions and natural resources in the Spratly Islands was published in Vietnamese by Science and Technology Publishing House in 1998 (Hanoi, Vietnam) [*Tran et al.*, 1998].

In the period 1996–2001, the China government was carried out the program "South China Sea Monsoon Experiment ("SCSMEX") to investigate the oceanography conditions

in the SCS and the Spratly Archipelago in particular, especially on the ocean-atmosphere interaction processes. In recent years, Chinese oceanographers have published many papers on meteorology and hydrodynamics in the SCS [*Cai et al.*, 2002; *Chao et al.*, 1995; *Shaw and Chao*, 1994, et al.].

Oceanographic studies in the Spratly Islands area were carried by Vietnam-Philippines Joint Oceanographic Marine Scientific Research Expedition in the South China Sea (JOMSRE-SCS: 1996–2007). Four expeditions "JOMSRE" (1996, 2000, 2004, 2007) were conducted (Figure 3).

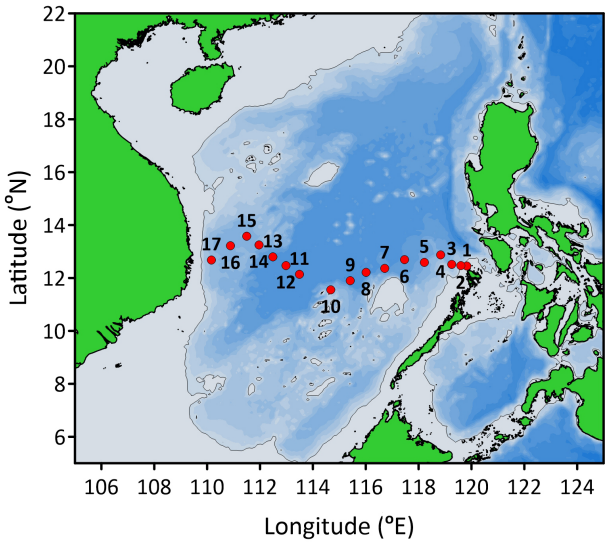

Figure 3. Vietnam-Philippines Joint Oceanographic Marine Scientific Research Expedition in the South China Sea of JOMSRE-SCS (JOMSRE II, 2000).

Vietnamese scientists, under various international and national marine research programs, have published a number of papers during 1993–2018 [*Bui et al.*, 2009; *Do et al.*, 2018; *Nguyen and Dang*, 2008; *Nguyen et al.*, 1999; *Nguyen*, 2000; *Nguyen et al.*, 1993; *Pham*, 2003].

Vietnam-Russia cooperation on meteorologic and hydrodynamic investigations in the SCS and the Spratly Islands area was carried out in 2011–2012 and in 2019–2020 between IO VAST and POI FEB RAS [*Le*, 2005; *Le et al.*, 2020, 2021b].

It should be noted that almost all published papers analyzing various aspects of atmospheric and marine physics, including tropical cyclones (typhoons), focused on the entire South China Sea and touched in passing on the Spratly Archipelago. The Spratly Archipelago is a disputed area of water between the countries surrounding the SCS, so investigations are classified information. Published papers on the study area are generally published in local languages in local journals. However, these were works on individual islands of the Archipelago. It is only recently, with the appearance of Japanese (JMA), Hong Kong Observatory (HKO) and American databases (NOAA), that more global studies have become possible. So meteorological parameters such as solar radiation, air temperature, monsoons, tropical cyclones, water evaporation, etc. were studied in the paper [*Le et al.*, 2020] directly over the water area of the Archipelago for the period 1884–2018. During this period, 218 tropical cyclones were identified, including 24 typhoons with the maximum wind speed of 64 m/s. However, this paper was published in a Vietnamese journal.

In recent years, studies on meteorological and hydrodynamic conditions in the Spratly Islands area have been carried out under the national project of Vietnam [*Le et al.*, 2021a].

In general, reviews and studies of the Spratly Archipelago are rather few and mainly focused on topography, geomorphology, coral reefs, and some marine species, without detailed studies of meteorological and hydrodynamic processes or climate change. In view of the above, marine research in the Spratly Archipelago is not sufficiently detailed, so further in-depth study of the area is needed.

It should be noted that the most dangerous hydrometeorological phenomenon in the SCS is the typhoon season, which brings catastrophic consequences for the surrounding countries. In addition, a significant number of typhoons travel to the Russian Far East, carrying a large amount of destructive energy and reaching the Bering Sea in a transformed form. As a rule, TC come to the Far Eastern Seas not in the phase of maximum development but in a weakened form (ex-typhoon). Nevertheless, they regularly lead to catastrophic consequences for the Russian Far East and have a significant impact on the general state of climate in this region. Thus, the importance of studying the interconnection of hydrometeorological processes not only in the SCS but also in the Far East becomes obvious. This has determined the joint efforts of Vietnamese and Russian scientists in this direction.

The Spratly Islands are the first to be hit by the typhoons that originate in the Western Pacific Ocean. Additionally, a number of typhoons originate directly in the SCS. Therefore, the study of the peculiarities of TC distribution is extremely important for the entire SCS and especially for the economic zone of the coast of Vietnam. We have for the first time statistically analyzed the variability and intensity of typhoons in the Spratly Archipelago over a period of more than a century.

The purpose of this paper is to analyze the inter-annual variation in the number and intensity of tropical cyclones in the Spratly Archipelago to determine possible environmental risks due to modern climatic changes.

The novelty of the work is that in addition to the well-known JMA, HKO and NOAA sites, meteorological data from Vietnamese meteorological stations of the islands (Spratly and Southwest Cay) of the Spratly Archipelago for the period 1987–2020 were used for the first time, providing more detailed information about this region. Moreover, this is the first this paper is published outside Vietnam.

This work is dedicated to the 100th anniversary of IO VAST in 2022 (Figure 4a), the 50th anniversary of POI FEB RAS in 2023 (Figure 4b), and the 70th anniversary of GC RAS in 2024 (Figure 4c).

Figure 4. Anniversary emblems: a – IO VAST, b – POI FEB RAS, c – GC RAS.

Data and Methods

In accordance with the research objective, we analyzed interannual changes in the number and intensity of tropical cyclones (TC) in the Spratly Archipelago without detailing their structure and internal dynamics.

In order to realize this goal, the necessary information for the period 1884–2020 was obtained from the available Internet resources: Regional Specialized Meteorological Centre Tokyo – Typhoon Center of Japan Meteorological Agency (JMA) (https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html); National Hurricane Center and Central Pacific Hurricane Center of the National Oceanic and Atmospheric Administration (NOAA), USA (https://coast.noaa.gov/hurricanes/). The data obtained include wind speed, radius of maximum wind speed, pressure at the center of the tropical cyclone, its position and trajectory. In addition, meteorological data from weather stations in the Spratly Archipelago for the period 1987–2020 was used, providing more detailed information about this region. It should be noted that the 1884–1944 data are not regular and not always accurate due to the small amount of data.

We used the Saffir–Simpson tropical cyclones scale used in National Weather Service, USA (Table 1), where tropical cyclones are considered those cyclones that have passed from a tropical depression to their filling. Tropical cyclones with speeds of 33 m/s or more in the Far East and Southeast Asia are called typhoons, and in North and South America they are called hurricanes.

Table 1. The Saffir–Simpson tropical cyclones scale used in National Weather Service, USA

Type	Category	Pressure, (mbar)	Maximum wind speed	
			(knots)	(m/s)
Tropical Depression	TD	–	< 34	< 17
Tropical Storm	TS	–	35–63	17–32
Typhoon/Hurricane	1	> 980	64–82	33–42
Typhoon/Hurricane	2	965–980	83–95	43–49
Typhoon/Hurricane	3	945–965	96–112	50–58
Typhoon/Hurricane	4	920–945	113–134	59–69
Typhoon/Hurricane	5	< 920	> 134	70+

Results and Discussion

Quantity of Tropical Cyclones

Tropical cyclones affecting the Spratly Islands area were found from the collected data, and then typhoons with wind speeds greater than 33 m/s on the Saffir–Simpson scale were selected (Table 2, Figure 5) [*Le et al.*, 2021b].

Table 2. Statistics of tropical cyclones based on Saffir–Simpson scale crossed in and adjacent the Spratly Islands area for period 1884–2020

	Tropical Depression	Tropical Storm	Typhoon	Total
Numbers of occurrence	146	58	25	229
Percentage (%)	63.76	25.32	10.92	100

The Table 2 shows that there were 25 typhoons (10.92%) with maximum wind speed (V_{max} > 33 m/s), 58 tropical storms (25.32%) with 17 m/s < V_{max} < 33 m/s, and 146 subtropical storms (63.76%) with V_{max} < 17 m/s. On average, there are 1.68 storms per year and this is quite high.

229 tropical cyclones were observed in the Spratly Islands area during the period 1884–2020 (Figure 5). Most of the tropical cyclones originated in the Northwest Pacific near the Philippines (60%), with the remainder forming in the SCS. Not all TC passed through the Spratly Archipelago, but they had a significant impact on the study region.

Annual Distributions

Figure 6 shows that the annual distribution of tropical cyclones in the study area is not regular. From 1884 to 1944 (data is not regular and not always qualitative), there was on average one tropical cyclone per year, but from 1945 to 2020, there was a rapid increasing trend in the number of tropical cyclones to about 2.5 per year. Specifically, in 2013 and 2017, there were six tropical cyclones per year each. In 1983, 1962, 1993, 1998, and 2019 there were five each year. In some years, tropical cyclones had no impact on the Spratly Islands area.

The trend is determined using a moving average over two periods. The value of reliability of approximation is equal to R^2 = 0.3132. Consequently, the scatter deviation of the data relative to trend is low because the data were uneven and not of high quality during the period 1844–1944.

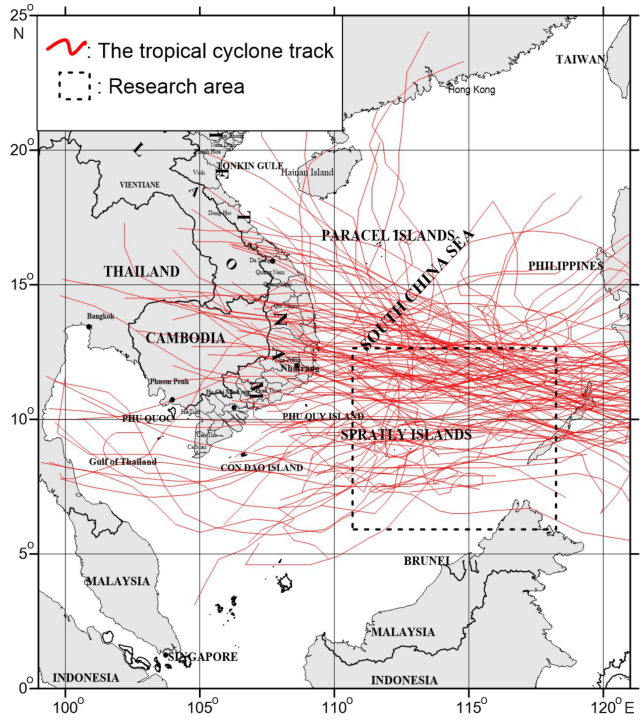

Figure 5. The tracks of the tropical cyclones that crossed and affected directly to the Spratly Islands Area (1884–2020).

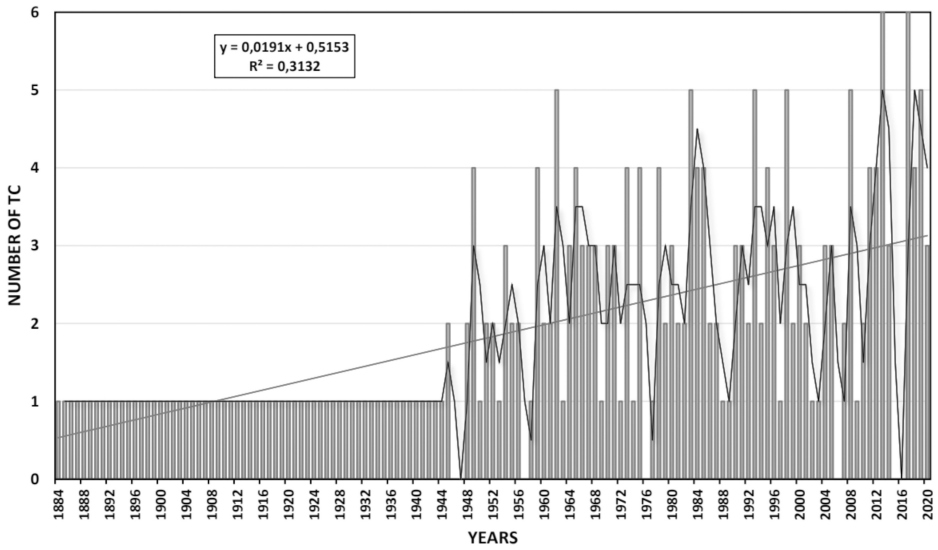

Figure 6. Yearly distribution of tropical cyclones affected to the Spratly Islands areas for period 1884–2020.

To sum up, trend is that the number of tropical cyclones developed gradually from 1884 to 2020.

Thus, a clear trend towards an increase in the number of typhoons over the Spratly archipelago is revealed. One of the possible reasons for this may be the intensive development of the East Asian monsoon with a strong tropical convergence zone under present climatic conditions. The noted trend in the future may become a serious source of regional climatic risks, so it requires, in our opinion, purposeful study.

We compared the annual distribution of typhoons in the SCS and the Spratly Archipelago for the period 1951–2019 (Table 3) [*Le*, 2005; *Vlasova et al.*, 2022]. 178 tropical cyclones in the Spratly Islands region versus 851 in the SCS. This suggests that the Spratly Archipelago

receives a fifth of all tropical cyclones of the SCS. Moreover, the number of typhoons affecting the Spratly Islands region was almost 20 times less (25 against 464). This is because typhoons were more frequently observed in the north of the SCS (over 12° N, i.e., above the Spratly Islands) and were more intense than in the rest of the sea. Nevertheless, these typhoons, not included in the statistics, also had a strong influence on the studied water area.

Table 3. Statistics of tropical cyclones based on Saffir–Simpson scale in the SCS and the Spratly Islands area (1951–2019)

	Tropical Depression	Tropical Storm	Typhoons	Total
South China Sea				
Numbers of occurrence	89	298	**464**	851
Percentage (%)	10.46	35.02	54.52	100
Spratly Islands				
Numbers of occurrence	102	51	**25**	178
Percentage (%)	57.30	28.65	14.04	100

Seasonal Fluctuations

The Spratly Islands area experiences two main storm seasons throughout the year: September through January the following year and February through August (Figure 7, Table 4). In the first storm season, the number of tropical cyclones was more than four times higher than in the second one. November is the month with the highest occurrence of 73 tropical cyclones (31.88%). Followed by December with 55 tropical cyclones (24.02%). Accounting for the third-highest frequency in October with 35 tropical cyclones (15.28%). January and September have a number of 12 tropical cyclones. The least TC month is July (3). Thus, it can be said that tropical cyclones occur frequently in the study area. The main storm season coincides with the strong northeast monsoon season. Therefore, tropical cyclones with heavy rain, high winds, and high waves cause many hindrances to economic and defense activities in the region's waters.

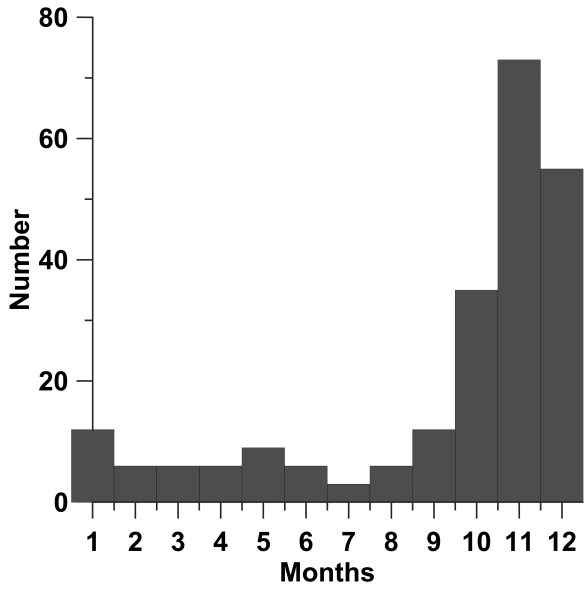

Figure 7. Monthly distribution of tropical cyclones affected to the Spratly Islands areas for period 1884–2020.

Table 4. Monthly distribution of tropical cyclones in the Spratly Islands area during 1884–2020

Storm season is from September through January next year							
Months	IX	X	XI	XII	I		
Numbers	12	35	**73**	55	12		
Percentage, (%)	5.24	15.28	31.88	24.02	5.24		
Storm season is February to August							
Months	II	III	IV	V	VI	VII	VIII
Numbers	6	6	6	9	6	3	6
Percentage, (%)	2.62	2.62	2.62	3.93	2.62	1.31	2.62

We compared the monthly distribution of typhoons in the SCS for the period 1951–2019 [*Le et al.*, 2020, 2021b] and in the Spratly Archipelago at the same period. The peak month in the SCS was September (146 TC). Such a month in the Spratly Archipelago was November (53 TC). The shift of the peak occurred after 2 months.

The reason is that the months with maximum storm frequency in the SCS are July, August, and September (between mid-summer to mid-autumn) that the period has the Inter-Tropical Convergence Zone (ITCZ) in the Northern Hemisphere, especially September. However, after that because the ITCZ ridge of continental high pressure moves to the south of the SCS, the time for storms to pass the study area occurred two months later than the northern part (Table 5, Figure 8).

Table 5. Monthly distribution of typhoons along the SCS and Spratly Islands area during 1951–2019

	South China Sea		Spratly Islands	
Months	Numbers	Percentage, (%)	Numbers	Percentage, (%)
I	16	1.88	11	6.18
II	7	0.82	4	2.25
III	10	1.18	6	3.37
IV	18	2.12	6	3.37
V	33	3.88	7	3.93
VI	67	7.87	6	3.37
VII	127	14.92	2	1.12
VIII	125	14.69	6	3.37
IX	**146**	17.16	7	3.93
X	121	14.22	29	16.29
XI	119	13.98	**53**	29.78
XII	62	7.29	41	23.03

The approximation reliability value for the SCS is R^2 = 0.5891 and for the Spratly Archipelago R^2 is 0.4919. The value of reliability of approximation for the SCS is R^2 = 0.5891, for the Spratly Archipelago – 0.4919. Consequently, the deviation of data scatter relative to the trend is acceptable.

Strongest Typhoons in Spratly Islands Area

The Spratly Archipelago is located in the southeastern part of the SCS, where tropical depressions can develop into tropical cyclones. 83 tropical cyclones formed in the Spratly Islands for period 1884–2020, of which 25 were typhoons (Table 6). Seven very strong typhoons with maximum wind speeds of more than 50 m/s were observed in the study area. These typhoons were AMY (December 1951), ELSIE (May 1954), LUCY (December 1962),

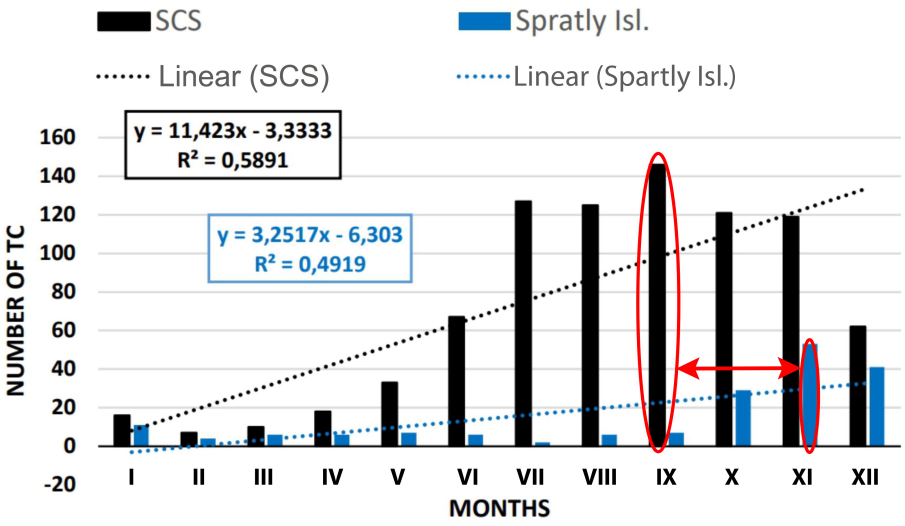

Figure 8. Comparison of monthly typhoon distributions in the South China Sea and Spratly Archipelago for the period 1951–2019.

SARAH (October 1979), AGNES (November 1984), ZACK (November 1995), and HAIYAN (November 2013). It can be seen that the highest category typhoons mainly occur during the fall and winter season. The causes of these cataclysms should be studied in a separate article, which will provide an additional option for possible forecasts. The weakest were typhoons DAMREY (November 2017) and NAKRI (November 2019). It should be noted that typhoon DAMREY moved very fast and unpredictably quickly reached the coastal waters of the economic zone of Vietnam, causing great socio-economic damage to its territory.

Figure 9 shows the path of 20 out of 25 strongest tropical cyclones to the Spratly Islands area for the period 1884–2020. The maximum wind speeds are summarized in Table 6 above. 20 high-intensity typhoons (shown in yellow, orange, red and purple colors) directly were affected the economic zone of Vietnam's Central Coast.

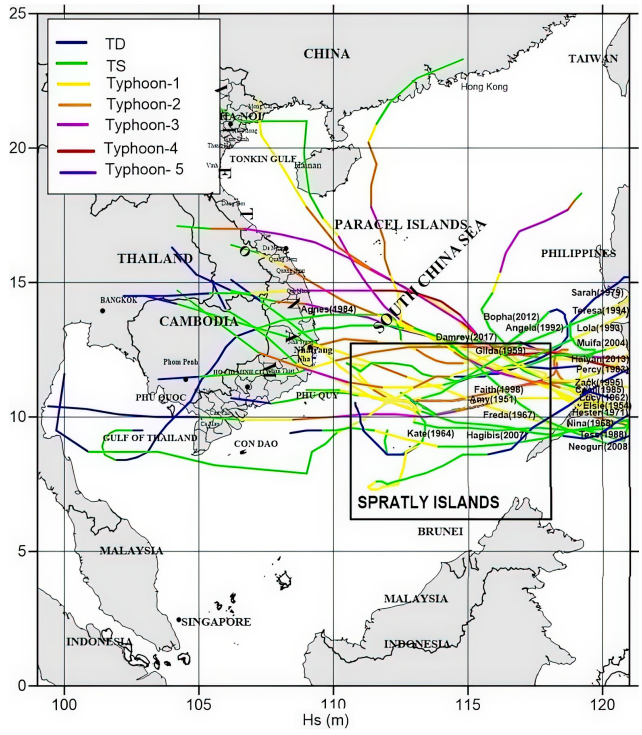

Figure 9. The track of 20 strongest typhoons effected Spratly Islands area during 1884–2020.

Table 6. Information of 25 strongest typhoons effected Spratly Islands area during 1884–2020

No.	Name	Time, month-year	Maximum wind speed, (kn)	Maximum wind speed in the Spratly Islands, (kn/m/s)
1	AMY	12–1951	120	100/51.4
2	ELSIE	05–1954	100	100/51.4
3	GILDA	12–1959	150	90/46.3
4	LUCY	12–1962	100	100/51.4
5	KATE	11–1964	80	80/41.2
6	FREDA	11–1967	85	85/43.7
7	NINA	11–1968	70	70/36.0
8	HESTER	10–1971	90	85/43.7
9	SARAH	10–1979	110	110/56.6
10	PERCY	11–1983	70	70/36.0
11	AGNES	11–1984	120	100/51.4
12	CECIL	10–1985	100	95/48.9
13	TESS	11–1988	65	65/33.4
14	ANGELA	10–1992	90	90/46.3
15	LOLA	12–1993	105	90/46.3
16	TERESA	10–1994	80	65/33.4
17	ZACK	11–1995	120	120/61.7
18	FAITH	12–1998	90	90/46.3
19	MUIFA	11–2004	115	90/46.3
20	HAGIBIS	11–2007	85	85/43.7
21	NEOGURI	04–2008	100	70/36.0
22	BOPHA	12–2012	140	80/41.2
23	HAIYAN	11–2013	170	125/64.3
24	DAMREY	11–2017	90	65/33.4
25	NAKRI	11–2019	65	65/33.4

Conclusion

The analysis of changes in the number and intensity of tropical cyclones over the Spratly Archipelago for the period 1888–2020 has shown the following:

- A clear trend is identified towards an increasing number of typhoons, which could be a major source of regional climate risks in the future. This is probably due to the intense development of the East Asian Monsoon with a strong tropical convergence zone under current climatic conditions.
- 229 tropical cyclones affected the study region. 25 strongest typhoons accounted for near 11% of the total number of TC, 58 tropical storms accounted for more than 25%. 146 tropical depressions, respectively, were near 64%.
- The frequency of TC is quite high: 1.68 tropical cyclones per year. The highest number of tropical cyclones per year (6) was observed in 2013 and 2017. Five tropical cyclones per year were observed in 1962, 1983, 1993, 1998, 2008, and 2019.
- The formation of tropical cyclones can be roughly divided into two seasons: September–January of the following year and March–August. The fall-winter season coincides with a strong northeast monsoon and more than four times the spring-summer season. November was the month with the highest frequency of TC occurrences, followed by December, and October was the third most frequent. The weakest month was July (3 TC).

- A clear trend towards an increase in the number of typhoons over the Spratly Archipelago has been revealed. One of the possible reasons for this may be the intensive development of the East Asian Monsoon with a strong tropical convergence zone under current climatic conditions. The noted trend may become a serious source of regional climatic risks in the future and requires, in our opinion, a targeted study.

Heavy rains, strong winds, and high waves always accompany tropical cyclones, which cause great hindrance to economic and defense activities in the study area, as well as bringing catastrophic consequences for nearby water areas.

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