Distribution features of the weather conditions in Nha Trang Bay (The South China Sea)

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Nha Trang Bay is a semi-envelop coastal basin. It is located on the west coast of the South China Sea as well as in the south of the central part of the Vietnamese coast. The climate of the bay belongs to the sub-equatorial zone or to the zone of equatorial-tropical monsoons. Determination of the meteorological characteristics of an ocean region, especially for nearshore bay waters, plays a very important role in the sustainable development of the social-economical system of Vietnam. This paper presents a spatial and temporal long-term analysis of several meteorological characteristics in Nha Trang Bay, such as wind, tropical cyclones, air temperature, air humidity, and rainfall. The meteorological data were collected from the Nha Trang meteorological station during 1977–2015 (wind data until 2020). The data for typhoons were extracted from the National Weather Service (USA) and the Japan Meteorological Agency during 1945–2015. Statistical methods for collecting and analyzing data to estimate the statistical parameters of meteorological characteristics were used in the study. A study of results shows that the meteorological characteristics in the Nha Trang Bay are a seasonal variation of the East Asian monsoon (northeastern-NE and southwestern-SW monsoons). The winds in Nha Trang Bay are the seasonal change, influenced by the NE monsoon from October to April and the SW monsoon from June to August. May and September are the transition periods. Nha Trang Bay has a temperate tropical climate because the temperature regime of the bay ranges from less than 25°C in the winter and more than 28°C in the summer. Extreme conditions, including typhoon activity and heavy rainfall (coinciding with high humidity), occurred in October, November, and December. *KEYWORDS:* Nha Trang Bay; the South China Sea; Meteorology; East Asian Monsoon.

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Introduction

Nha Trang Bay is a semi-envelop coastal basin. It is located on the west coast of the South China Sea as well as in the south of the central part of the Vietnamese coast (Figure 1). It ranges from 12°11′ N to 12°28′ N and 109°08′ E to 109°28′ E (from the Electronic information gate of Khanh Hoa Province, Vietnam). Furthermore, it is located opposite the sea and directly interacts with land-sea processes. The bay involves many islands

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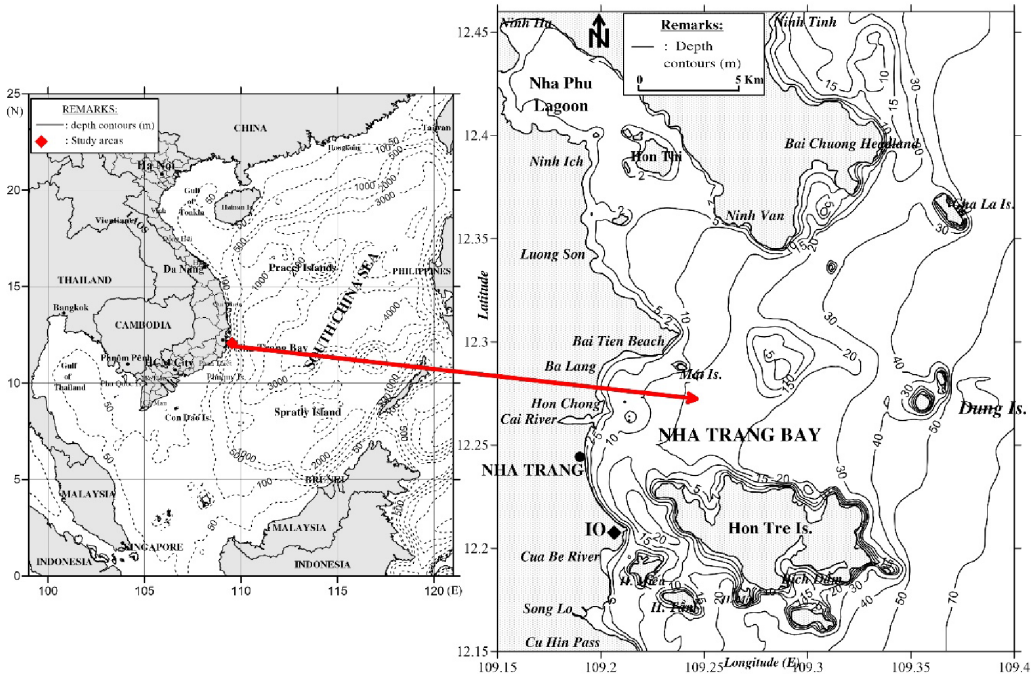

Figure 1. Location of Nha Trang Bay in the South China Sea and at the Vietnamese Coast.

and headlands. Fresh water discharges into the bay from the Cai River in the north and the Cua Be River in the south. The continental shelf is relatively narrow, with a depth contour of 50 m in the area of the bay mouth. The bottom sediment is fine sand. The total suspended sediment (TSS) concentration is low. The climate of the bay belongs to the sub-equatorial zone or to the zone of equatorial-tropical monsoons. A clearly pronounced seasonal variation of air temperature is observed here: winter is colder than summer, and the speed of winter wind is greater than summer. Three large-scale circulation atmospheric systems are observed in this zone: trade winds, equatorial troughs, and especially the monsoons. The first two are characterized by exceptional constancy and stability, and the monsoons are characterized by periodicity. In the conditions of the East Asian monsoon, which prevails over the entire South China Sea and in particular over Nha Trang Bay, northeastern winds prevail in winter and southwestern winds in summer. Therefore, the winter monsoon is called the northeastern (NE), and the summer monsoon, the southwestern (SW). Against the background of large-scale circulation systems, synoptic and mesoscale systems are observed tropical disturbances, which, under favorable conditions, develop into tropical storms. For example, in November 2017, the strongest typhoon ever recorded, Damrey, passed with catastrophic consequences.

Atmospheric processes (atmospheric circulation, trade winds, monsoons, typhoons, etc.) over the South China Sea, including meteorological parameters (wind, air temperature, humidity, rainfall, etc.), form climatic conditions not only for all nearby countries but also affect the weather of the entire Asia-Pacific region. Tropical cyclones (typhoons) occupy a special place among atmospheric processes. The main destructive effect of typhoons occurs in the Southeast Asia region. However, a significant number of its are directed towards the Russian Far East, with the outflow of a large amount of destructive energy [*Vlasova et al.*, 2021].

Besides, specific meteorological conditions are formed in the coastal regions of the South China Sea (bays, fjords, river mouths, etc.), which affect on the weather of the territory.

The determination of the meteorological characteristics of nearshore ocean regions, especially for the Nha Trang Bay, plays a very important role in the sustainable development of the social-

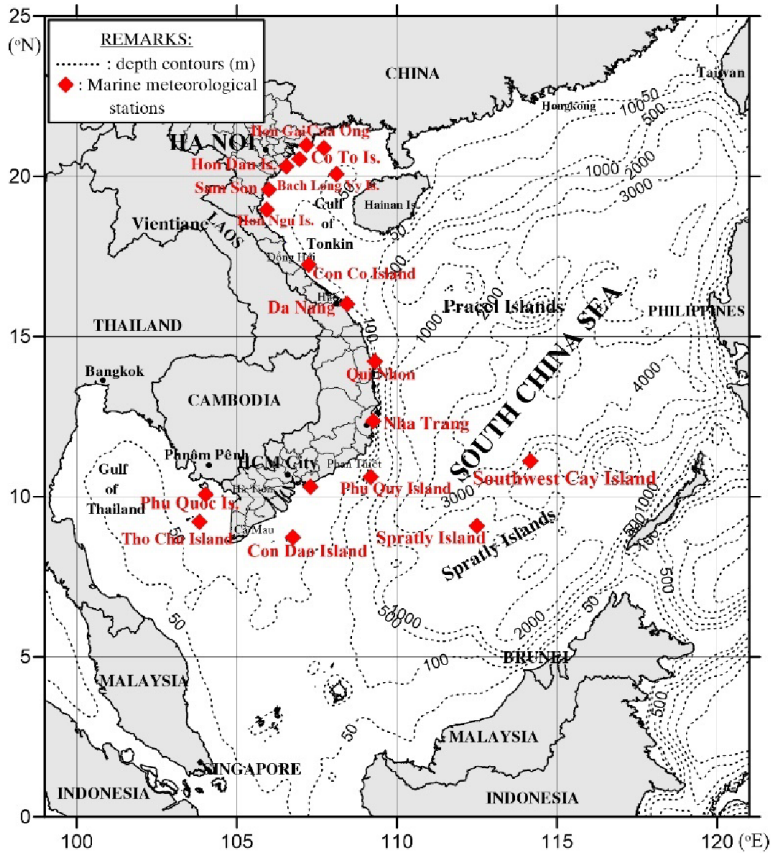

Figure 2. Distribution of main marine meteorological stations of Vietnam.

economical infrastructure of the Vietnam government. In recent years, the economy in Nha Trang Bay has rapidly developed, especially in tourism, maritime, mariculture, shore protection, etc., and has become a significant social-economical place for Khanh Hoa Province in particular and Vietnam in general. In connection with the above, the study of the meteorological characteristics in Nha Trang Bay, the heart of the sea waters of South Vietnam, becomes obvious.

Phu Lien meteorological station in Hai Phong City has been the first meteorological station in Vietnam since 1902, and the Nha Trang meteorological station was established in 1906 by the French. However, the historic data of all meteorological stations in the South of Vietnam (including Nha Trang station) was broken because of the war's impact. So, the uninterrupted data collected from 1977 to the present. In addition, at present time, the number of main marine meteorological stations in Vietnam are 18. They are managed by the Vietnam Meteorological and Hydrological Administration [*Le et al.,* 2015]. These stations include (from north to south): Cua Ong ward, Hon Gai city, Co To Island, Bach Long Vy Island, Hon Dau Island, Sam Son city, Hon Ngu Island, Con Co Island, Da Nang city, Quy Nhon city, Nha Trang city, Phu Quy Island, Vung Tau city, Con Dao Island, Phu Quoc Island, Tho Chu Island, Southwest Cay Island, Spratly Island (Figure 2). At these stations, the meteorological parameters were observed and recorded, such as wind, air temperature, humidity, precipitation, visibility, fog, etc.

The first attempts to analyze meteorological characteristics in Vietnam were made in 1902 at Phu Lien station by the French [*Youth Daily Newspaper online in Vietnam,* 2019]. The first weather station was opened in 1906, and the first analysis of meteorological parameters in Nha Trang Bay was done in 1906 by the French (Archived data in the Department of Meteorology and Hydrology for Southern Central Vietnam). In 2004, the Depart-

ment of Science and Technology, the Khanh Hoa Province published a monograph on climatic and hydrological features in the Khanh Hoa Province including Nha Trang Bay [*Department of Science and Technology, Khanh Hoa Province,* 2004]. But there are practically no papers in which the analysis of meteorological parameters for a long-term period was carried out in Nha Trang Bay.

In recent years, the Institute of Oceanography, Vietnam was carried out different projects which were related to the marine meteorological conditions especially wind and typhoons, in the Nha Trang Bay.

The main projects were:

- the Vietnam–Russia collaboration project (2011–2012) on the study of marine meteorological, hydrological, and dynamical investigations, Subproject No. 2, Project No. 19-Project 47;
- the Vietnam-Russia collaboration project (2019–2021) on the study of the structure and dynamics of the Vietnam waters (No. VAST19-020 and QTRU02.04/19-20);
- provincial project (2017–2019) on the study of the hydrometeorological features in Khanh Hoa Province waters;
- Vietnam National Project (2017–2022) on the study of some interaction processes between sea, atmosphere, and land, and environmental variation corresponding to the context of global climate change within the framework of the IOC/WESTPAC program (No. DTDL.CN-28/17).

Research on these projects were published in the following papers [*Le,* 2005, 2008; *Le and Pham,* 2007; *Le et al.,* 2010, 2020, 2021; *Pham et al.,* 2015; *Vlasova et al.,* 2016, 2020].

The National Center for Hydro-Meteorological Forecasting (Vietnam) is forecasting the marine meteorological information for the different areas along the Vietnamese coast. However, the forecasting data from global, neighboring countries, and the Vietnam National Center for Hydro-Meteorological Forecasting are useful for the region as a whole and are not correct for the nearshore study basin of Nha Trang Bay. In this case, the grid resolution of forecasting data was coarse when compared to the nearshore basin area. Therefore, the data source used for the meteorological study of the nearshore study basin is better collected from a local long-term observed data station.

The accumulated material by this time provided the basis for analyzing the spatial and temporal variability of meteorological characteristics over a long-term period: for typhoons for the period 1945–2015 and for the main meteorological characteristics for the period 1977–2015 (for wind up to 2020) in the Nha Trang Bay.

An important aspect of the work is its novel approach to a description of the features that give each ocean region its character. The two core principles are: the use of the most modern database for all maps of regional distributions of properties and a discussion of all observed features within a frame of reference developed for atmospheric dynamics, rather than based on a simple geographical approach.

The purpose of our work is to study the long-term spatial and temporal variability of meteorological characteristics in Nha Trang Bay for the period 1977–2020.

Data and Methods

Data Sources

We collected data on the average monthly air temperature, rainfall, and air humidity from the Nha Trang Meteorological Station during 1977–2015 at six hourly intervals (0 h, 6 h, 12 h, and 18 h of Greenwich). We also collected wind data from 1977 to 2020 by the Department of Meteorology and Hydrology in Southern Central Vietnam. Furthermore, we collected the data of typhoons that crossed the coastline from 12° to 13°N, in the Nha Trang Bay for the period 1945–2015 from websites of the USA National Weather Service (https://sharaku.eorc.jaxa.jp/TYP_DB/links1_e.html) and of the Japanese Meteorological Agency (https://www.jma.go.jp/bosai/map.html#4/49.153/132.979/&elem=root&typhoon=all&lang=en&contents=typhoon). These websites provide access to a wealth of typhoon information, including charts on the track of the storm, plus a text, based table of tracking information. We considered the features, such as the velocity of forwarding motion and wind speed.

Table 1. The Beaufort Wind Scale

Force	Wind (Knots)	Wind (m/s)	WMO Classification
0	Less than 1	< 0.3	Calm
1	1–3	0.3–1.5	Light Air
2	4–6	1.6–3.3	Light Breeze
3	7–10	3.4–5.4	Gentle Breeze
4	11–16	5.5–7.9	Moderate Breeze
5	17–21	8.0–10.7	Fresh Breeze
6	22–27	10.8–13.8	Strong Breeze
7	28–33	13.9–17.1	Near Gale
8	34–40	17.2–20.7	Gale
9	41–47	20.8–24.4	Strong Gale
10	48–55	24.5–28.4	Storm
11	56–63	28.5–32.6	Violent Storm
12	64+	> 32.7	Hurricane

Table 2. Saffir-Simpson Hurricane Intensity Scale

Type	Category	Pressure (mb)	Maximum sustained wind speed (knots)	(m/s)
Tropical Depression	TD	–	< 34	< 17
Tropical Storm	TS	–	35–63	18–32
Hurricane	1	> 980	64–82	33–42
Hurricane	2	965–980	83–95	43–49
Hurricane	3	945–965	96–112	50–58
Hurricane	4	920–945	113–134	59–69
Hurricane	5	< 920	> 134	70+

Methods

We used in the study the statistical methods for collecting and analyzing data to estimate the statistical parameters of meteorological characteristics, such as wind, air temperature, rainfall, and humidity [*WMO,* 1966]. We used the classifications of the winds based on the Beaufort wind scale and of the typhoons based on the Saffir/Simpson typhoon scale for the correct estimation of the statistical parameters (Table 1, Table 2). We calculated the wind frequency based on the Beaufort scale and then drew the rose diagram.

We took the methods for analyzing the vertical structure of wind speed and monitoring observed wind characteristics from onshore stations to offshore from the "Shore Protection Manual" [*SPM,* 1984] and the "Coastal Engineering Manual" [*CEM,* 2002]. These guides also provide a knowledge base on seasonal meteorological trends (hurricane season, winter storms) and long-term environmental trends (sea level rise, climate change).

Results and Discussion

Wind Regime

The wind in Nha Trang Bay is the seasonal change influenced under the NE monsoon (October–April), with the N, NE, and NW directions. And under the SW monsoon (June–August), with the SE direction of the influence of land-sea breeze, the wind direction is becoming east. May and Septem-

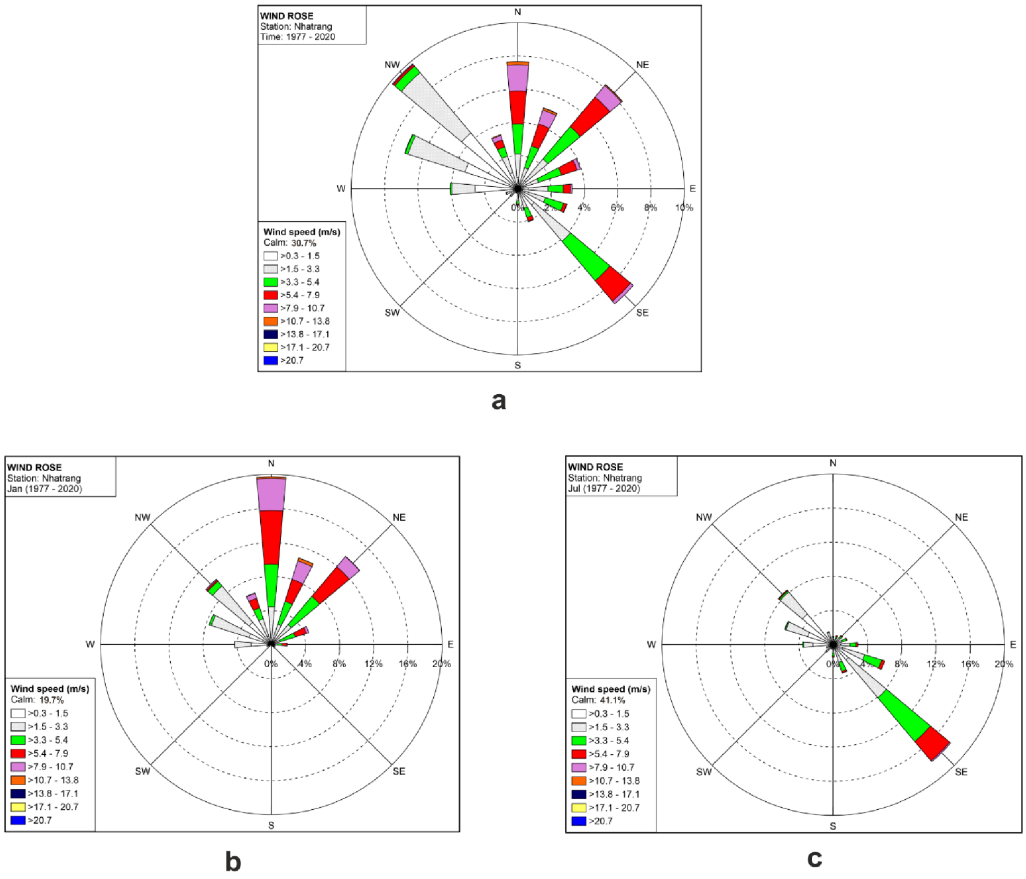

Figure 3. The wind rose diagram in Nha Trang Bay for the period 1977–2020 (%): a – the average long-term wind rose diagram in Nha Trang Bay; b – the average long-term wind rose diagram in January (NE monsoon) in the Nha Trang Bay; c – the average long-term wind rose diagram in July (SW monsoon) in Nha Trang Bay.

ber are the transition periods. The characteristics of the wind regime in the onshore region of Nha Trang Bay are for the period 1977–2020 (Figure 3, Table 3, Table 4, Table 5).

The three wind rose diagrams (Figure 3) illustrate the direction and wind speed changes in Nha Trang Bay from 1977 to 2020. There are three main features during this period. Figure 3a (Table 3) shows the average long-term data affected by the two monsoons (NE and SW). Figure 3b (Table 4) shows the average long-term data in January, the typical month for the NE monsoon. And Figure 3c (Table 5) shows the average long-term data in July, the typical month for the SW monsoon. Let's take a closer look at this.

The average long-term wind rose diagram and average long-term wind frequency in the Nha Trang Bay during the period show the influence of the NE and SW monsoons (Figure 3a, Table 3). The percentages of the NW, N, and NE directions show the impact of the NE monsoon, and the figure of SE shows the impact of SW. At the top of the directions was the NW direction, with just nearly 10%. The second most popular was the SE direction, at 9%, followed by the NE and N direction, both at just near 8%. Additionally, the wind calm had a frequency of 30.7% (100%–69.3%). At the same time, the wind speed changed from 1.5 m/s to 8 m/s with a dominant frequency of 47% (22.7% + 14.4% + 9.8%), and the wind speed changed from 0 to 1.5 m/s and over 8.0 m/s with a negligible frequency of 22% (17.7% + 4.2% + 0.5%).

Figure 3b (Table 4) shows the wind rose diagram (wind frequency) of January – the typical month in the NE monsoon. The wind from the N direction had the largest frequency at 19.7%. The

Table 3. Average Long-Term Wind Frequency (%) at the Nha Trang Station for the Entire Period 1977–2020

Wind force (Beaufort scale)	N	NNE	NE	ENE	E	ESE	SE	SSE	S
I	0.7	0.4	0.6	0.4	0.6	0.5	1.3	0.3	0.3
II	1.4	1.0	1.7	0.9	1.2	1.3	2.8	0.9	0.4
III	1.8	1.4	2.5	1.4	0.9	1.1	3.1	0.6	0.2
IV	2.0	1.4	2.3	1.0	0.4	0.2	1.6	0.2	0.1
V	1.6	0.9	0.9	0.2	0.1	0.0	0.2	0.0	0.0
VI	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.7	5.2	8.1	3.9	3.2	3.1	9.0	2.0	1.0

Wind force	SSW	SW	WSW	W	WNW	NW	NNW	Calm	Total
I	0.2	0.5	0.6	2.6	3.3	4.4	1.0	–	17.7 ($0.3 \leq V \leq 1.5$)
II	0.1	0.1	0.2	1.4	3.6	4.7	1.0	–	22.7 ($V > 1.5,\ V < 8$)
III	0.0	0.0	0.0	0.1	0.2	0.5	0.6	–	14.4 ($V > 1.5, V < 8$)
IV	0.0	0.0	0.0	0.0	0.0	0.1	0.5	–	9.8 ($V > 1.5, V < 8$)
V	0.0	0.0	0.0	0.0	0.0	0.0	0.3	–	4.2 ($V \geq 8$)
VI	0.0	0.0	0.0	0.0	0.0	0.0	0.1	–	0.5 ($V \geq 8$)
Total	0.3	0.6	0.8	4.0	7.1	9.7	3.5	30.7	69.3

V – wind speed $\sum = 100$

next tops of the frequencies were NE and NW directions have the frequencies respectively 13.5 and 10.0%. In addition, ENE and W directions was at just under 5%. The wind speed from 0.3 m/s to 8 m/s changed with the dominat frequency of 70.7% (12.6% + 24.2% + 17.0% + 16.9%). And the wind speed over 8.0 m/s changed with the negligible frequency of 9.6% (8.9% + 0.7%). The wind calm had a frequency of 19.7% (100% − 80.3%).

Figure 3c (Table 5) shows the wind rose diagram (wind frequency) of July – the typical month of the SW monsoon. In this connection, the wind direction becomes east. There were two main directions (SE and NW), which had frequencies of 17.9% and 8.4%, respectively. The total of E, S, and W directions was just around 7.7%. Additionally, the wind speed changed from 0.3 to 5.5 m/s with a frequency of 54.5% (20.1% + 21.5% + 12.9%). The wind calm was 41.1% (100% − 58.9%).

As can be seen from Table 6, the wind reaches its maximum values in winter. The highest wind speed was observed in November at 30 m/s.

At the Nha Trang station, during the period from 1977 to 2020, the average long-term wind speed was 3.4 m/s, with monthly fluctuations of 2.6–4.7 m/s (Table 7).

The month with the highest average wind speed is usually in the period of the strong northeast monsoon (from November to February next year). The strongest wind speeds of the day can reach levels of 7–8 on the Beaufort Scales, which can knock down trees, houses, etc., especially under the influence of the strong northeast monsoon and typhoons.

Table 4. Average Long-Term Wind Frequency (%) at the Nha Trang Station in January (1977–2020)

Wind force (Beaufort scale)	N	NNE	NE	ENE	E	ESE	SE	SSE	S
I	0.8	0.4	0.7	0.3	0.2	0.0	0.1	0.1	0.0
II	3.6	2.1	2.4	0.8	0.5	0.1	0.2	0.0	0.0
III	5.0	2.8	4.3	1.8	0.5	0.1	0.2	0.0	0.0
IV	6.3	2.7	4.5	1.4	0.5	0.1	0.0	0.0	0.0
V	3.8	2.3	1.6	0.3	0.1	0.1	0.0	0.0	0.0
VI	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	19.7	10.7	13.5	4.6	1.8	0.4	0.5	0.1	0.0

Wind force	SSW	SW	WSW	W	WNW	NW	NNW	Calm	Total
I	0.0	0.1	0.4	2.4	2.7	3.4	1.0	–	12.6 ($0.3 \leq V \leq 1.5$)
II	0.0	0.1	0.1	1.9	4.6	5.6	2.2	–	24.2 ($V > 1.5, V < 4$)
III	0.0	0.0	0.0	0.0	0.3	0.7	1.3	–	17.0 ($4 < V < 6$)
IV	0.0	0.0	0.0	0.0	0.0	0.2	1.2	–	16.9 ($6 < V < 8$)
V	0.0	0.0	0.0	0.0	0.0	0.1	0.6	–	8.9 ($V > 8, V < 11$)
VI	0.0	0.0	0.0	0.0	0.0	0.0	0.1	–	0.7 ($11 \leq V < 14$)
Total	0.0	0.2	0.5	4.3	7.6	10.0	6.4	19.7	80.3

V – wind speed $\sum = 100$

Typhoon Regime

The 58 tropical cyclones that reached Nha Trang Bay for the period 1945–2015 (over a 71-year), had both directional and non-directional impacts on the bay (Figure 4a). Among them, 12 typical directional typhoons (Figure 4b) from tropical depressions to typhoons of Category 5 (hurricane) were observed in the Nha Trang Bay. In general, during this period, there were 27 typhoons with a maximum wind speed ($V_{\max}$) of more than 33 m/s, 16 tropical storms with 17 m/s $< V_{\max} <$ 33 m/s and 15 subtropical storms with a $V_{\max} <$ 17 m/s (Table 8).

From Figure 5, the average long-term distributions of tropical cyclones at Nha Trang Bay were not regular. There was a long period when the average long-term number of cyclones was low just around 0.8 cyclones/year. From 1945 to 1952, the number was lower, then the number from 1963–1999 was a little higher. Finally, between 2005 and 2012, the number was approximately the average value. The number of tropical cyclones reached a peak (3 tropical cyclones) in 1959. However, there were lots of years that did not appear storms, especially those allocated to two periods: 1953–1958 and 2000–2004. In the rest of the years, there were two cyclones per year.

As for the average long-term monthly distribution of tropical cyclones, then occurrences of tropical cyclones were mostly in September (10.34%), October (27.59%), November (41.38%), and December (12.07%) (Table 9, Figure 6).

Table 5. Average Long-Term Wind Frequency (%) at the Nha Trang Station in July (1977–2020)

Wind force (Beaufort scale)	N	NNE	NE	ENE	E	ESE	SE	SSE	S
I	0.6	0.4	0.5	0.4	0.9	1.1	2.3	0.6	0.5
II	0.2	0.4	0.5	0.6	1.0	2.7	5.8	1.6	0.4
III	0.1	0.2	0.3	0.5	0.7	2.1	6.7	1.1	0.4
IV	0.0	0.1	0.1	0.1	0.2	0.4	3.0	0.2	0.1
V	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.9	1.1	1.4	1.6	2.8	6.3	17.9	3.5	1.4

Wind force	SSW	SW	WSW	W	WNW	NW	NNW	Calm	Total
I	0.3	0.8	0.6	2.4	3.1	4.7	0.9	–	20.1 ($0.3 \leq V \leq 1.5$)
II	0.1	0.3	0.2	1.0	2.7	3.4	0.6	–	21.5 ($V > 1.5, V < 4$)
III	0.1	0.1	0.1	0.1	0.1	0.2	0.1	–	12.9 ($4 < V < 6$)
IV	0.0	0.0	0.0	0.0	0.0	0.1	0.0	–	4.3
V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	0.1
VI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	–	0.0
Total	0.5	1.2	0.9	3.5	5.9	8.4	1.6	41.1	58.9

V – wind speed $\sum = 100$

Table 6. Maximum Long-Term Wind Speed at the Nha Trang Station (1977–2020)

Months	Directions	Max Speed (m/s)
I	NNE	20
II	ENE	20
III	ENE	18
IV	NNE	15
V	WSW	24
VI	SSW	19
VII	W	15
VIII	SW	19
IX	N	20
X	N	26
XI	NE	30
XII	N	27

According to *Le* [1999], the typhoon season in the South China Sea is from June to December. And in October, the typhoon's track is usually to the west and direct towards the Central Coast. Also, in November and December, the average trajectory of the typhoon completely moved to the south (12–13°N) and slightly to the southwest, heading to the coast of South-Central and Southern Vietnam due to the influence of the continental high-pressure tongue.

Air Temperature in Nha Trang Bay

Table 10 shows the average long-term monthly air temperature in Nha Trang for the period 1977–2015, from which it can be seen that the minimum values (less than 25°C) are in the winter period, and the highest (more than 28°C) – in the summer. The hottest month is June, the coldest one is January. From Table 10, we also see that the average long-term range of daily temperature change in Nha Trang Bay was just over 6°C. The average long-term range of daily temperature change was

Table 7. The Average Long-Term Monthly Wind Speed at the Nha Trang Station (1977–2020)

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
(m/s)	4.2	4.0	3.7	3.3	2.9	2.6	2.6	2.7	2.6	3.1	4.1	4.7	3.4

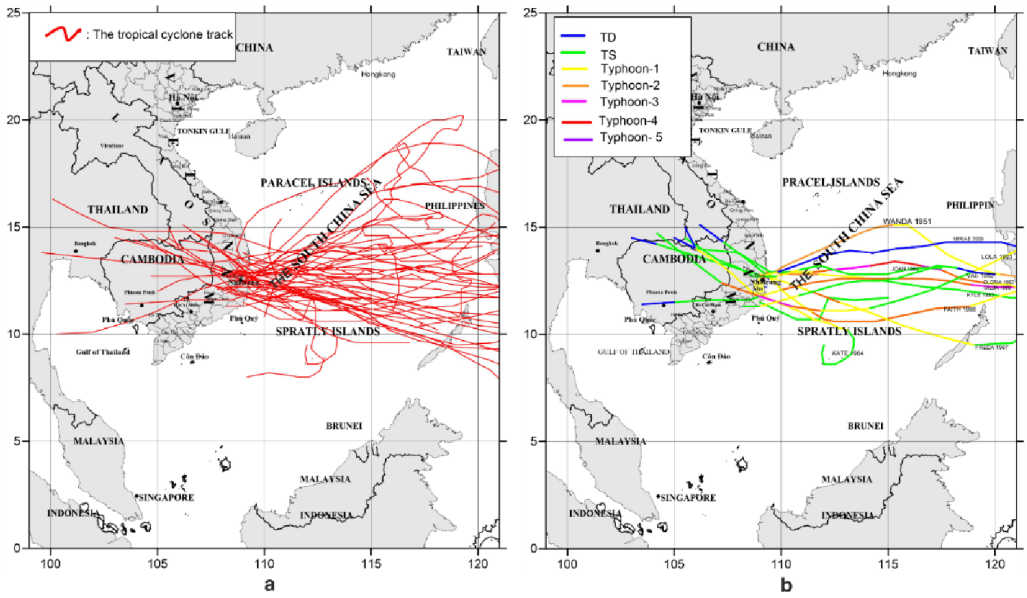

Figure 4. The trajectories of tropical cyclones that affected Nha Trang Bay for the period 1945–2015: a – the trajectories of 58 of tropical cyclones; b – the trajectories of 12 typical tropical cyclones.

Table 8. Statistics of Tropical Cyclones Based on Saffir-Simpson Scale

Tropical cyclones	Tropical Depression	Tropical Storm	Hurricane (Typhoon 1–5)	Total
Numbers of occurrence	15	16	27	58
Percentage (%)	25.86	27.59	46.55	100

the lowest in November and December, at 4.9°C. August was the highest, with 6.9°C. The maximum long-term range of daily temperature change in Nha Trang Bay happened in May and June, at 12.0°C.

Compared with all of Vietnam, the weather in Nha Trang is pleasant. It is not too hot in the summer, and the short winter is not very cold. The maximum temperature in the Nha Trang station between 1977 and 2015 reached a peak of 37.9°C on August 7th, 1976. Additionally, the minimum temperature in the Nha Trang station was the lowest at 15.8°C on January 10th, 1984 and December 25th, 1999 (Table 10).

Table 11 shows the average long-term annual and monthly rainfall, as well as rainfall in dry and rainy seasons for the period 1977–2015. The rainy period was observed in the fall-early winter (more than 350 mm), the dry period – the rest of the time (less than 60 mm), except for the month of May (more than 100 mm). There are many reasons why it rains in Nha Trang Bay, such as storms, monsoon, and the intertropical convergence zone. From January to April, a gradually weakening northeast

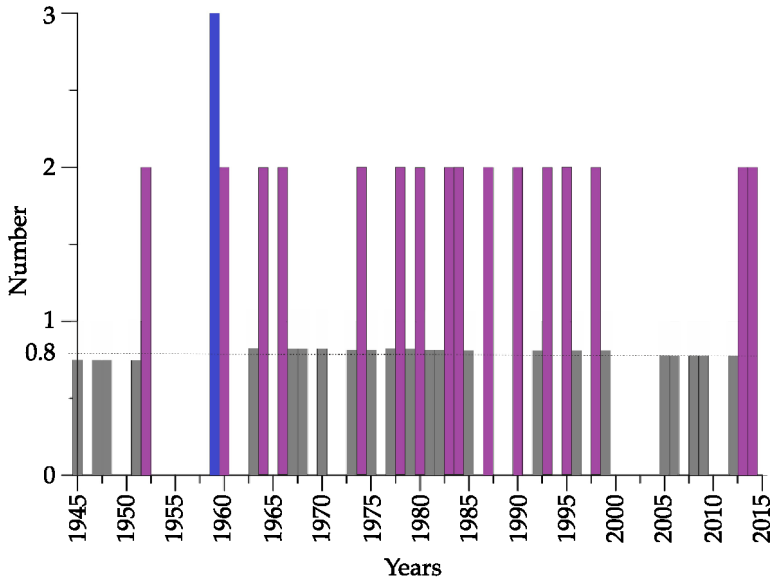

Figure 5. The average long-term distribution of tropical cyclones affected on Nha Trang Bay for the period 1945–2015.

Table 9. The Average Long-Term Monthly Distribution of Tropical Cyclones in Nha Trang Bay for the Period 1945–2015

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Numbers	0	0	2	0	1	2	0	0	6	16	24	7	58
Percentage (%)	0	0	3.45	0	1.72	3.45	0	0	10.34	27.59	41.38	12.07	100

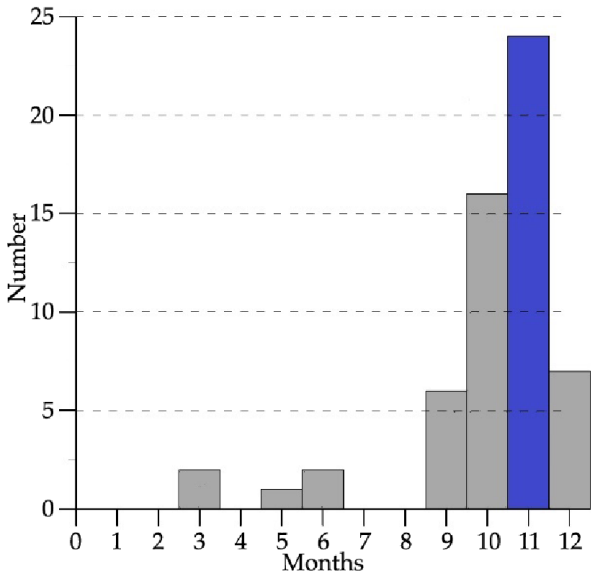

Figure 6. The average long-term monthly distribution of tropical cyclones affected on Nha Trang Bay during 1945–2015.

monsoon dominates Nha Trang, so the values of average monthly rainfall are often lower than 60 mm. May (after May 21st) and June usually have rain and small floods in a short period because of the tropical convergence zone in early summer. The SW monsoon weakens slightly in August and September. For several reasons, from September to December, was the wet season in Nha Trang Bay. The southwest monsoon is gradually weakening in these months, and the northeast monsoon, on the contrary, has become is active strongly. The cold air masses are strengthening continuously to the south, combining the activities of tropical convergence zone, tropical cyclones, and high-altitude east wind disturbances.

Air Humidity

The average long-term monthly air humidity for the period 1977–2015 is illustrated in Table 12. The

Table 10. The Average Long-Term Monthly Air Temperature and the Range of Average (Maximum) Long-Term Daily Air Temperature Change in Nha Trang Bay (1977–2015)

	Monthly			Daily range	
Months	T (°C)	T_{max} (°C)	T_{min} (°C)	Average T (°C)	Maximum T (°C)
I	24.0	30.5	15.8	5.5	9.9
II	24.6	31.6	17.0	5.9	9.8
III	25.8	32.7	17.8	6.2	11.4
IV	27.5	34.6	19.7	6.3	10.4
V	28.5	37.2	22.7	6.7	12.0
VI	28.8	37.4	22.6	6.7	12.0
VII	28.5	36.9	22.0	6.8	10.9
VIII	28.6	37.9	22.7	6.9	11.6
IX	27.8	37.1	22.1	6.6	11.8
X	26.6	33.5	19.1	5.6	9.6
XI	25.7	32.5	18.6	4.9	9.5
XII	24.5	31.8	15.8	4.9	10.9
Year	26.7	37.9	15.8	6.1	10.8

Table 11. The Average Long-Term Monthly Rainfall in Nha Trang (1977–2015)

Month	Rainfall (mm)
I	41.1
II	10.1
III	58.8
IV	26.8
V	106.1
VI	38.7
VII	33.5
VIII	38.0
IX	202.2
X	344.1
XI	350.6
XII	198.4
$\sum$ year	1448.4
Rainy season rainfall (September–December)	1095.3
Dry season rainfall (January–August)	353.1

Table 12. The Average Long-Term Monthly air humidity (%) in Nha Trang Bay (1977–2015)

Months	Average (%)	Minimum (%)
1	79	42
2	80	35
3	80	41
4	80	41
5	79	37
6	77	33
7	77	35
8	77	35
9	80	33
10	83	42
11	82	47
12	80	46
year	79	39

long-term annual variation of relative humidity is both influenced by the temperature regime and also by the rain regime. The period with the lowest humidity is usually in the months of June, July, and August at around 77%. While the period of highest the humidity is from September to December, reaching 83% (coinciding with the rainy season). The average humidity varies from month to month, by only 1–2%. At the end of the dry season and the beginning of the rainy season, the difference in air humidity is 3–6%. The long-term annual range of relative humidity averages 6–7%.

Conclusions

All investigations of meteorological parameters (wind, typhoons, air temperature, air humidity, and rainfall) in Nha Trang for the period 1977–2015 confirmed the influence of the East Asian monsoon (NE and SW monsoons).

- Winds in Nha Trang Bay have the seasonal variability. In the NE monsoon (October–April) with the main N, NE, and NW directions, in the SW monsoon (June–August) with the main SE direction. May and September are the transition periods. A remarkable phenomenon is that during SW monsoon (summer) Nha Trang Bay is influenced by the SE wind direction (it is blowing from sea to land). In addition to this, in summer, all areas along the coast of Central Vietnam are strongly influenced by hot and dry southwestern winds. Therefore, the weather in Nha Trang is windy;

- The long-term annual distributions of tropical cyclones in Nha Trang Bay were not regular. In the period the average occurrence of cyclones was low, just around 0.8 cyclones/year. Occurrences of tropical cyclones were mostly in September (10.34%), October (27.59%), November (41.38%), and December (12.07%). The extreme conditions, including typhoon activity, and heavy rainfall, occurred in October, November, and December;

- The air temperature regime in Nha Trang Bay shows that the minimum values are less than 25°C in winter, and the highest, more than 28°C in summer. The hottest month is June, the coldest is January. That means it shows that Nha Trang Bay has a temperate climate;

- The rainy period was observed in the fall-early winter (more than 350 mm). The dry period is the rest of the time (less than 60 mm), except for the month of May (more than 100 mm). The long-term average yearly rainfall was 1449.4 mm, the average long-term rainy season rainfall (from September to December) was 1095.3 mm, and the average long-term dry season rainfall (from January to August) was 354.1 mm;

- The period with the lowest humidity is usually in the months of June, July, and August at around 77%, while the period of the highest humidity is from September to December, reaching 83% (coinciding with the rainy season).

In general, Nha Trang Bay is influenced by the tropical climate. The typical weather characteristics are relatively harmonious, especially during the windy weather (summer). The weather is typically warm and mild nearly all year round. As such, it has long been a popular destination for sunbathing, swimming, and enjoying beach activities for both domestic and foreign tourists.

The long-term meteorological characteristics in Nha Trang Bay are important primarily for the economy of Vietnam, but also for the climatic conditions of the neighboring region, as well as for the navigation of ships, both domestic and international.

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