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The monthly average distributions of sea-surface wind speeds and directions in the East Vietnam Sea

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ABSTRACT

This paper analyzes a monthly global gridded sea-surface wind dataset from Jan 1991 to Dec 2020, sourced from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). The goal is construct schematic maps depicting the monthly average distributions of sea-surface wind speeds and directions in the East Vietnam Sea. These maps provide a visual representation of the monsoon patterns at different points and areas in the region. The statistical and analytical findings reveal that the East Vietnam Sea is primarily influenced by two types of monsoons: Northeast and Southwest. When one is strong, the other is weak, and vice versa. The Northeast monsoon dominates from September to April of the following year, while the Southwest monsoon is more dominant from May to August. The intensity of the Northeast monsoon is usually greater than that of the Southwest monsoon. These results provide an overview of the monsoon distributions in the East Vietnam Sea, which can assist scientists and managers in proposing policies and measures suitable to the climate environment and wind seasons. These findings also help in the effective exploitation of abundant wind energy resources in coastal Vietnam and the East Vietnam Sea. Furthermore, the results are consistent with previous studies of monsoons in the East Vietnam Sea, indicating that the data source used in this study is reliable and can be utilized as input data for tidal, currents, or oil spread models.

Keywords: Monsoon, wind speed and direction distributions, Southeast Asian Studies, Vietnam East Sea, wind energy, wind power.

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INTRODUCTION

Wind is the movement of air from areas of high pressure to areas of low pressure caused by the unequal heating of Earth's surface by the sun, which creates different zones with varying air different pressure [1, 2]. The hottest regions are typically found near the equator, while the North and South Poles are the coldest. Various types of winds are classified based on their periodicity, location, and direction, such as monsoon winds, global winds, local winds, and trade winds [3, 4]. Different regions of the world are affected by distinct types of winds at various times of the year.

In the early 1900s, German climate scientist Wladimir Koppen identified five primary climate types across the globe: tropical, dry, temperate, continental, and polar [5]. The East Vietnam Sea (EVS) has a tropical climate primarily influenced by two monsoons: the Northeast and Southwest monsoons [6]. The Northeast monsoon dominates during winter, while the Southwest monsoon is more prevalent in the summer, hence their winter and summer monsoon designations.

Since ancient times, humans have been known to exploit wind energy for many different purposes. For example, using a sailboat as a means of transportation, a windmill to grind grains, or pump water [7]. In addition, wind turbines are increasingly used by countries worldwide to generate electricity by converting the kinetic energy of the wind into motion energy. According to the Statistical Review of World Energy 2020, wind energy produced approximately 1,600 TWh of electricity, which accounts for over 5% of worldwide electrical generation and about 2% of energy consumption [8]. Wile, and energy is considered a clean, sustainable, and renewable energy source with a significant lower environmental impact than fossil fuel combustion.

The Asia Pacific region is projected to become the largest offshore wind power market by 2030, with Vietnam identified as the most promising offshore wind market in Southeast Asia, according to the Global Offshore Wind Report 2020 [9]. However, the Global Wind Report 2021 highlights that Vietnam's wind market is at an inflection point and presents an opportunity to accelerate into a rapid growth phase to meet the country's increasing demand for electricity, ensure energy security, and deliver socio-economic benefits through a renewable-led pathway. Additionally, the Prime Minister's approval of numerous wind projects in 2020 illustrates Vietnam's commitment to becoming the leader in wind energy development in Asia [10].

Wind energy is a promising source of clean and sustainable energy with a smaller environmental impact than fossil fuels. However, its successful use relies heavily on climate knowledge, including wind distribution, intensity, periodicity, and location [11]. The wind speed distribution at a specific location determines the available wind energy, making the collection of accurate and long-term wind field data critical for estimating future electricity production and calculating the economic viability of a project [12]. There have been numerous studies to support wind power development in Vietnam and globally. For instance, research has shown that the global wind power potential for 2000 was estimated at approximately 72 TWh, which could supply all the world's energy needs. However, practical barriers must be overcome to realize this potential [13]. To facilitate wind energy development for both utility-scale generation and village power, a study used the MesoMap model *(mesoscale atmospheric simulation model and mass-conserving wind flow model)* to build the wind resource maps of Southeast Asia with 2 elevations (30 m and 60 m) [14]. Another study based on wind data collected hourly from 2001–2010 at eight locations in Vietnam showed that Nha Trang, Ca Mau, and Quy Nhon have the best potential for wind power farm development in the country [15]. In Southern Vietnam, a study analyzed and evaluated four wind farms, finding that all could produce 2,265 GWh annually, and 3-MW wind turbines were the most efficient with the fewest losses for generating wind energy [16]. Additionally, using Etap software to simulate power flow and the impact of wind power plants on the power system, another study identified three wind power planning areas in

Soc Trang province, totaling 37,340 ha with a capacity of 1,470 MW and an average wind speed of 6–6.5 m/s at an altitude of 74 m [17]. These studies and others like them provide crucial information for policymakers, investors, and developers seeking to expand wind energy in Vietnam and beyond.

This objective of this study is to analyze the monthly average distributions of sea-surface wind speeds and directions in the EVS, with goal of providing valuable insights to scientists and managers. The wind distribution data can inform decision-making related to climate environment and the development of policies to harness the abundant wind energy in this area. In addition, as the EVS is a critical region for sea transport routes connecting the Pacific-Indian Ocean, Europe-Asia, and the Middle East-Asia [18, 19], this study can also benefit navigators and fishermen by providing options suitable for their routes or seasons. With these insights, stakeholders can make informed decisions to optimize their operations and maximize the potential benefits of the wind energy in this region.

MATERIALS, STUDY AREA AND METHODS

Materials

In this study, the datasets used include:

The monthly global gridded sea-surface wind dataset with the one-degree resolution of latitude and longitude for 1991 to 2020 was acquired from the NOAA-ESRL Physical Sciences Laboratory, Boulder, Colorado from their Website at https://psl.noaa.gov/data/gridded/. This International Comprehensive Ocean-Atmosphere Data Set (ICOADS) offers marine surface data spanning 1662-present, freely distributed worldwide. The ICOADS contains observations from many different observing systems encompassing the evolution of measurement technology over hundreds of years, and it could be considered the complete collection of marine surface data in existence [20].

The General Bathymetric Chart of the Oceans (GEBCO) released the global bathymetric product developed through the Nippon Foundation-GEBCO [21]. This product has a spatial resolution of 15 arc-seconds (~ 450 m), including bathymetric and the boundary, which is used to display the color depth and determine the boundary between the sea and land of the study area.

Study area

The study water area is the East Vietnam Sea, limited from longitude 99^{o}E to 120^{o}E, and latitude from 5^{o}N to 25^{o}N, as depicted in Fig. 1. This area includes the East Vietnam Sea and adjacent waters, which have a predominately tropical climate and are almost only influenced by two Northeast and Southwest monsoons [22].

Methods

The monthly global gridded wind dataset from the NOAA-ESRL Physical Sciences Laboratory, is stored in the NetCDF (Network Common Data Form) format. The wind data is split into zonal (u) and meridional (v) wind velocities. The wind data from these files is extracted and stored in a Microsoft Access database for the study area. The analysis and statistics for the study were performed from this database through mathematical and statistical functions in Microsoft Access. Fig. 2 illustrates the wind data table in this database.

There are 124,516 wind values in the wind dataset used for the study. These values are stored corresponding to 360 months (1/1991–12/2020). Therefore, about 346 wind values evenly distributed spatially in the study area monthly. The study area and the spatial distribution of collected wind data are described in Figure 1.

The movement of the wind is determined by speed and direction. The wind direction is the direction from which the wind is blowing, represented mathematically by a vector. The wind arrows (vectors) point in the direction the wind is blowing towards, and the length of the arrows denotes speed (u and v are the two components of the wind vector). The angle of the vectors is measured counterclockwise from the east or u-axis as depicted in Figure 3.

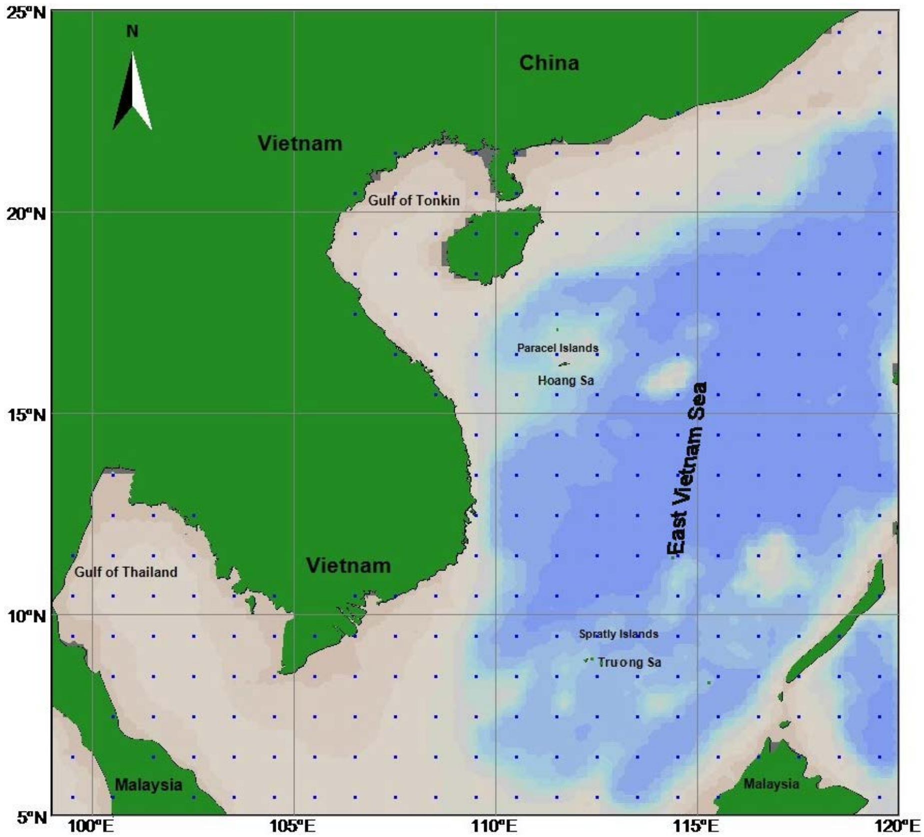

Figure 1. The study area and the spatial distribution of collected wind data

MonthlyWindData

Station_Code	Longitude	Latitude	sYear	sMonth	Uwnd	Vwnd
290960	118.5	24.5	1991	1	-5.639999	-7.5
290961	119.5	24.5	1991	1	-6.099991	-9.119995
290962	120.5	24.5	1991	1	-6.300003	-9.73999
290964	122.5	24.5	1991	1	-3.479996	-3.740005
290965	123.5	24.5	1991	1	-4.990005	-0.8300018
290966	124.5	24.5	1991	1	-3	-0.8999939
290985	117.5	23.5	1991	1	-7.849991	-7.770004
290986	118.5	23.5	1991	1	-6.970001	-8.319992
290987	119.5	23.5	1991	1	-6.429993	-11.66
290988	120.5	23.5	1991	1	-10.63	-20.03
290989	121.5	23.5	1991	1	-2.169998	-0.5299988
290990	122.5	23.5	1991	1	-6.209991	-2.399994
290991	123.5	23.5	1991	1	-6.910004	-1.459991
290992	124.5	23.5	1991	1	-5.539993	-2.459991
291008	114.5	22.5	1991	1	-4.459991	-2.459991
291009	115.5	22.5	1991	1	-7.550003	-5.580002
291010	116.5	22.5	1991	1	-8.080002	-7.849991
291011	117.5	22.5	1991	1	-6.679993	-7.319992
291012	118.5	22.5	1991	1	-5.029999	-9.550003
291013	119.5	22.5	1991	1	-4.089996	-9.679993
291014	120.5	22.5	1991	1	-0.6799927	-1.649994

Record: 1 of 124516 No Filter Search

Figure 2. Illustration of the wind data table in Microsoft Access Database

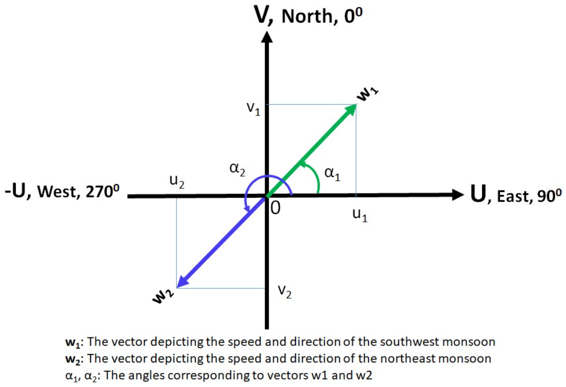

Figure 3. Illustration of the vector showing the wind speed and direction

Because the study area is almost only influenced by two types of the Northeast and Southwest monsoons, in the data analysis and statistics process, the components of the northeast and southwest monsoons are calculated separately. The components of the Northeast monsoon are determined by the angle with degrees ranging from 34 degrees to 56 degrees, and the components of the Southwest monsoon are determined by the angle with degrees ranging from 214 degrees to 236 degrees [23]. Arithmetical statistics are performed separately for each component *u*, *v* of the wind vector when calculating the monthly average wind speed.

RESULTS

The statistical and analytical results of the monthly average distributions of sea-surface wind speeds and directions in the EVS, are described in Figures 4–6. Figure 4 depicts the average distributions of sea-surface wind speeds and directions in the VES for Jan-Feb-Mar and Apr; Figure 5 depicts the average distributions of sea-surface wind speeds and directions in the VES for May-Jun-Jul and Aug, and Figure 6 depicts the average distributions of sea-surface wind speeds and directions in the VES for Sep-Oct-Nov and Dec. A comprehensive and visual overview of the monthly average wind strength in the study area, charts have been built to describe the monthly sea-surface wind speed average (m/s) (Figure 7).

In addition, based on the above average distributions (Figure 4–6), the analyzed results show that Vietnam's South-Central Sea, which is limited from Binh Thuan province to Binh Dinh province, Vietnam (corresponding to the sea area limited from latitude 10°N to 14°N, and longitude from 109°E to 110°E), usually has extreme wind intensity. Therefore, in the data analyzing process, the monthly average wind speed of Vietnam's South-Central Sea region is calculated separately to assess the wind energy potential. These results are presented in Table 1.

Based on the above statistical and analytical results (Figures 4–6), there are some comments as follows:

The study area is almost only influenced by two types of the Northeast and Southwest monsoons. The Northeast monsoon dominates from September to April the following year, while the Southwest monsoon is more dominant from May to August (Figures 4–6). When the Northeast monsoon is strong, the Southwest monsoon is weaker, and vice versa.

In general, the Northeast monsoon is stronger than the Southwest monsoon. The Northeast monsoon reaches its maximum average wind speed value (9.63 m/s) in the November of the winter season, gradually decreases in the spring, and usually reaches the minimum average wind speed value (3.65 m/s) in the July of the summer season, then rises gradually again in the autumn (Figure 7). The southwest monsoon is most active from May to August with wind speeds ranging from 5.28 m/s to 6.59 m/s, and it usually reaches its maximum average wind speed value in July (Figure 7). April and August are transitional months between these two monsoons. April is the transition month between the Northeast monsoon to the Southwest monsoon, while August is the transition month between the Southwest monsoon to the Northeast monsoon.

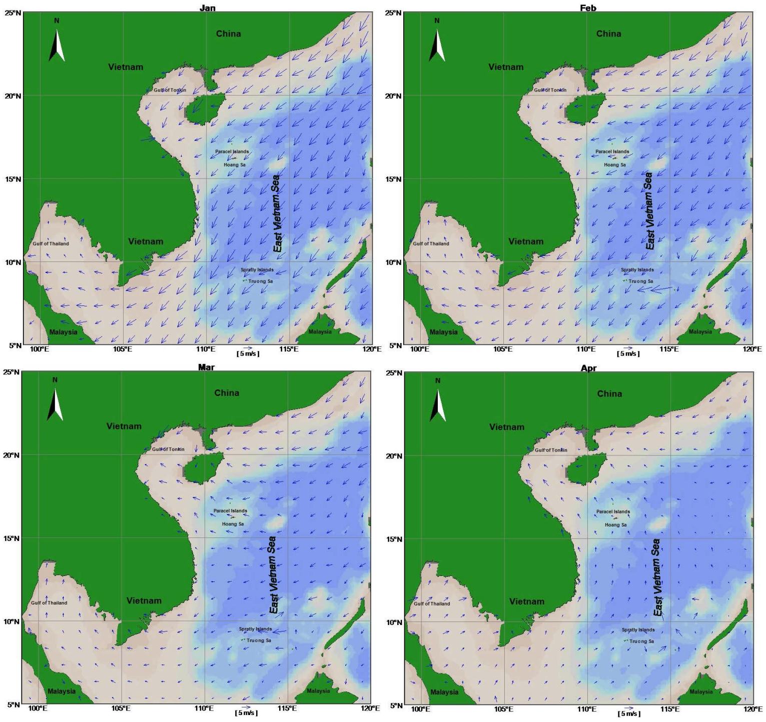

Figure 4. The average distributions of sea-surface wind speeds and directions in the VES for Jan-Feb-Mar and Apr

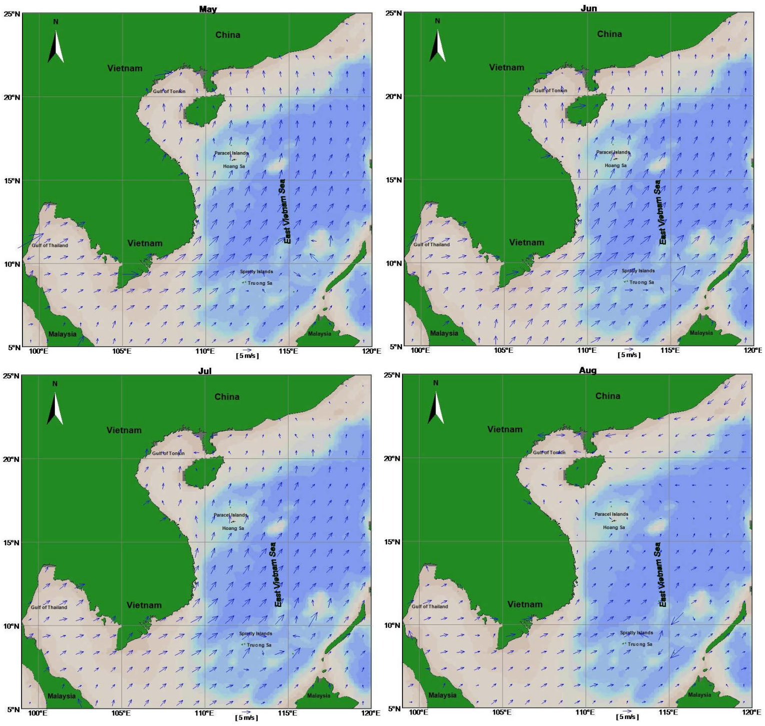

Figure 5. The average distributions of sea-surface wind speeds and directions in the VES for May-Jun-Jul and Aug

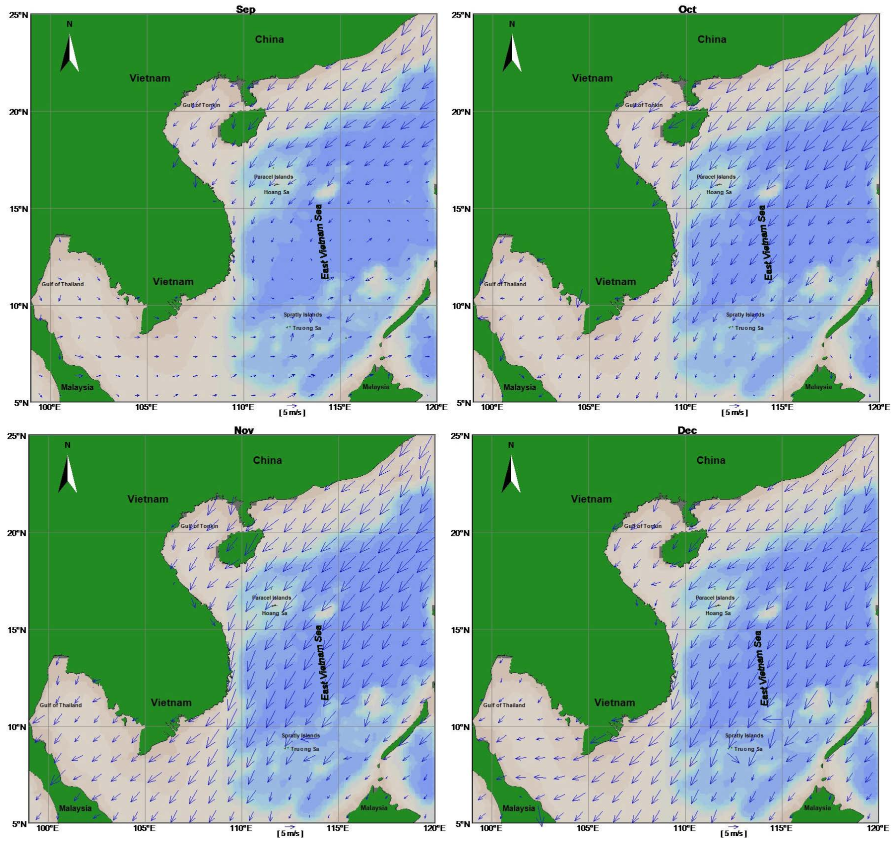

Figure 6. The average distributions of sea-surface wind speeds and directions in the VES for Sep-Oct-Nov and Dec

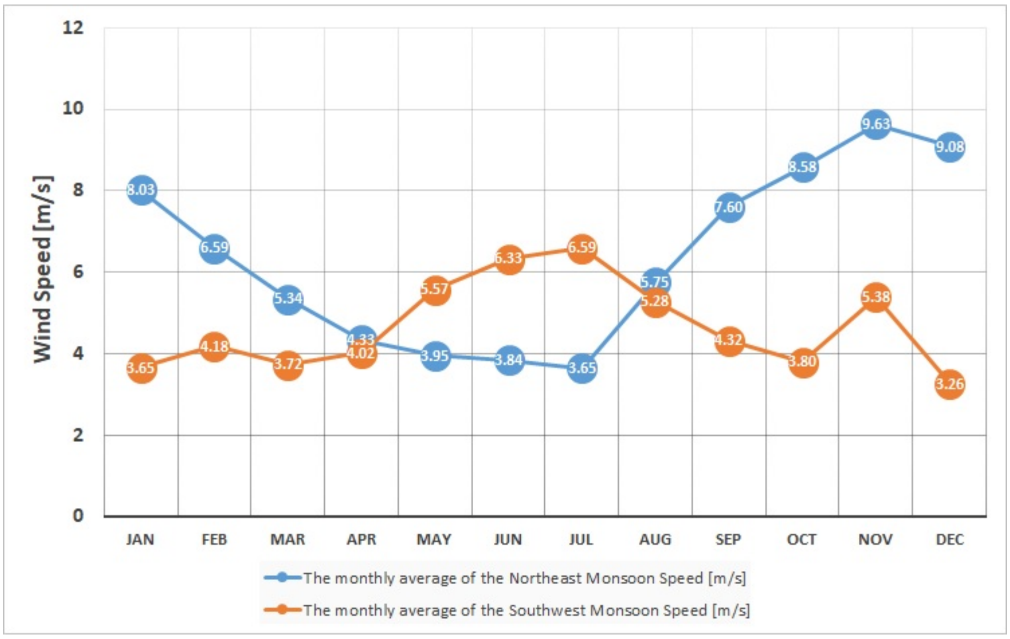

Figure 7. The monthly sea-surface wind speed average [m/s] in the VES

Different monsoons affect each area in the East Vietnam Sea at different times. Especially in October, the Northern sea of the East Vietnam Sea (from latitude 15^{o}N back to the North) is strongly affected by the Northeast monsoon, while the southern sea is still under the influence of the Southwest monsoon. In addition, Vietnam's South-Central Sea is the place most affected by the Northeast and Southwest monsoons (Figures 4, 6). Moreover, the calculation results of the monthly average wind speed have shown that the wind intensity of this region is often considerable, ranging from 4.31 m/s to 11.18 m/s, and the yearly average wind speed is 7.09 m/s (Table 1). These speeds are significant, equivalent to Beaufort's wind force scale 4 [24].

Table 1. Monthly average wind speed (m/s) in Vietnam's South-Central Sea

Months	Monthly average wind speed (m/s)
1	7.91
2	5.81
3	4.31
4	4.44
5	6.71
6	7.37
7	7.77
8	5.27
9	5.17
10	8.52
11	11.18
12	10.59
Yearly average wind speed: 7.09 (m/s)	

DISCUSSIONS

The above analysis shows that the Northeast and Southwest monsoons most affect Vietnam's South-Central Sea. Also, the wind data used in this study are for the sea surface at 10 m. According to observed data at a wind measuring station in Nha Trang city, Vietnam, the annual mean wind speed is 11.5 m/s [15], making this area have great potential for wind energy in Vietnam [25]. In practice, the wind strength is stronger at higher altitudes.

In addition, due to the topography of Vietnam's South Central Coast region, which ranged from 11^{o}N to 15^{o}N, the Northeast and Southwest monsoons changed their direction and blew parallel to the shoreline (Figure 4–6), creating longshore currents. The longshore current has a North-to-South direction during the dominant Northeast monsoon. This current causes a cyclonic gyre off the coast from Da Nang to Khanh Hoa, Vietnam (13^{o}N–15^{o}N) [26, 27]. In contrast, the longshore current has a South-to-North direction during dominant Southwest monsoons, which is one of the causes of creating an anticyclonic gyre off the coast from Ninh Thuan to Binh Thuan, Vietnam (11^{o}N–13^{o}N). This anticyclonic gyre is the leading cause of the upwelling phenomenon in the South-Central Sea of Vietnam [28-31].

CONCLUSION

Based on the analysis, the following conclusions can be drawn:

The study has created schematic maps that show the monthly average distributions of sea-surface wind speeds and directions in the EVS, providing readers with a visual representation of the monsoon distributions at different locations and times.

The EVS is primarily influenced by two types of monsoons, the northeast and southwest, which alternate in strength throughout the year. The Northeast monsoon dominates from September to April, while the Southwest monsoon dominates from May to August.

Different areas of the EVS are affected by different monsoons at different times, with the South-Central Sea being the most affected area, with a yearly average wind speed of 7.09 m/s.

The intensity of the northeast monsoon is generally greater than that of the Southwest monsoon. The Northeast monsoon reaches its maximum average wind speed in November and its minimum average wind speed in July, while the southwest monsoon is most active from May to August, with its maximum average wind speed occurring in July.

April and August are transitional months between the two monsoons, with April being the transition month from the northeast monsoon to the Southwest monsoon, and August being the transition month from the southwest monsoon to the Northeast monsoon.

These results can be useful for policymakers and managers in developing appropriate measures for utilizing wind energy resources in coastal Vietnam and for navigators and fishermen in planning their routes and activities.

The study's results are consistent with previous studies on monsoons in the EVS, indicating that the data source used in this study is reliable and can be used for other models such as tidal, currents, or oil spread models.

Overall, the study provides valuable insights into the monsoon patterns in the East Vietnam Sea and their implications for various stakeholders, which can inform decision-making and planning in the region.

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