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Western Lampung Offshore Wind and Wave Data Correlation Analysis

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Abstract: Wind and waves are the two most dominant environmental parameters in the sea. The availability of these two data is crucial in the design process of offshore and onshore buildings and the development of renewable energy from wind or wave. Numerous analyses have been done on each parameter, but none have tested their correlation specifically in the waters of the western Lampung. This study aims to find a correlation between these two parameters. The study used 20 years of wind and wave data from BMKG. The average wind speed data obtained was about 4,17 - 5,13 m/s. The mean significant wave height obtained was about 1,89 - 2,09 m. BMKG gives more direction with a huge wind-blowing duration (more than 500 hours), wind-blowing direction data are dominantly from SSE, WNW, and WSW. However, wave direction data is going to N and NE. This study found no correlation between wind and wave direction on the Western Lampung Offshore. Based on data from the time series of wind and wave that have been analyzed, continuously higher wind speeds result in higher wave heights.

Keywords: *Wave height, Wind speed, Wind-wave correlation, Lampung water*

Introduction

Lampung is a province located in the southern part of Sumatra Island, Indonesia. The province boasts a lengthy coastline stretching from the west to the east, which borders the Sunda Strait to the southeast. Lampung has a sea area of 24,820 km^2, a coastal area of 440,010 hectares, a coastline spanning 1,182 km, and is home to 132 small islands.

The coastline along the eastern region of Lampung extends from the northeast to the southeast, creating a predominantly straight shoreline with a sloping beach [1]. Similar to other open ocean beaches, the conditions on the western coast of Lampung are steep [2]. Meanwhile, the southeastern gulf waters of the Lampung province that faces the Sunda Strait is a region that has a lot of small islands [3], [4].

As a coastal province, activities conducted in Lampung waters are highly influenced by weather conditions, such as wind and waves. To ensure the safety and efficiency of various human activities at sea, such as tourism, transportation, fishing, oil and gas exploration, and exploitation industries, a good understanding of marine weather and climate conditions is critical [5], [6], [7], [8], [9], [10]. For further research, wind, waves, and their correlation can be valuable for developing local renewable energy [11].

For example, fishing is a maritime industry that is highly susceptible to weather conditions. In the event of unfavorable weather conditions, like high waves or strong wind, the cost of fishing is higher because fishermen have to travel more often to catch fish [12], [13]. In addition, if conditions worsen, fishermen may not be able to go to sea at all. With a potential national catch of 12,541,438 tons, bad weather could render this value useless [14]. Another example in the transportation sector, the bad weather that occurs every year is often detrimental both in terms of economy and life at the Bakauheni-Merak crossing [15], [16], [17].

Wind and waves are some parameters of sea weather conditions. Wind and wave characteristics such as wind speed, direction, and wave height depend heavily on the geographical location. Those characteristics are crucial in analyzing a phenomenon or problems like wave climate-related analysis [18], wave-to-wave interaction [19], assessment of ship reliability [20], impact on offshore structures [21], [22], and coast impact assessment [23].

The waves of the sea can be caused by winds, ocean tides, earthquakes, volcanic eruptions, landslides, and ships moving. Waves could be generated by all things that make a volume of water have sufficient momentum to propagate [24]. Among these wave generators, wind is the most dominant that can generate waves all the time at the sea. As there is difficulty in collecting wave data in the ocean wind data could be used to determine significant wave height and period [25], [26]. It is therefore necessary to know the characteristic relationship between waves and winds in the Lampung waters.

Method

Data and Location

The Western Lampung offshore location being analyzed in this research is shown in **Figure 1** and the coordinate is shown in **Table 1.** This study uses six points spread along the offshore of Western Lampung. These six points are about 50 kilometers away from the coast. The whole point is in the area of transition between the West Indian Ocean waters to the Western Lampung waters.

Figure 1. Western Lampung research location.

From these locations, wind and wave data will be analyzed. The wind and wave data originates from the Indonesian Meteorological, Climatological, and Geophysical Agency based on a meteorological model. Wind data was obtained in terms of 10 m wind speed and direction in each hour, with the model employing a horizontal resolution of 0.5° to 1.5° (approximately 55 to 160 km). This resolution balances computational efficiency and spatial coverage, leveraging readily available local meteorological wind data to get accurate findings [25]. The data is typically available for download at hourly intervals for the past and future forecast periods, with forecast data spanning up to 3 days ahead in 3-hour increments [27], [28]. Numerous other studies use the model's data and appear to be quite dependable [8], [11], [25], [29], [30], [31], [32], [33], [34].

Table 1. Research location coordinate.

No	Longitude (°)	Latitude (°)
1	103.25	-5.25
2	103.50	-5.50
3	103.75	-5.75
4	104.00	-6.00
5	104.25	-6.25
6	104.50	-6.50

Wave data was obtained in terms of significant wave height, period, and direction. The wind direction used is in 'blowing from'. Whereas the wave direction used was 'going to'. The data used in this analysis covered the 20 years from 2001 to 2020. In comparison to some sort of research, the number of years invested appears sufficient [29], [30]. This period includes severe weather situations as well as weather abnormalities that occur years later, thus it appears to provide comprehensive results.

Data Analysis

Analysis of the direction of winds and waves as the first step in data processing is critical to understanding the unpredictability of both of these maritime environment characteristics. This analysis is performed by determining the proportion of winds blowing in the same direction as the period of the analysis. The substantially same direction that is meant here is the commonly used compass direction. The results of this analysis are frequently given in windrose formats. The same applies to wave characteristics displayed as windrose, and waverose. The correlation between the wind direction and the wave direction was discovered once both parameters were understood.

When the wind blows in the same compass direction, it is categorized as the same wind event. Duration analysis is utilized to ascertain the length of time during which the wind generally blows in the same direction. The importance of this knowledge is the input it serves in the hindcast analysis commonly performed in ocean engineering when wave data are not available. The outcomes of this analysis support the comprehension gained from the cardinal direction analysis expressed as a percentage. The same methodology is applied to waves. Once both parameters have been analyzed, it becomes possible to establish the correlation between the dominant winds and the propagating waves.

During a wind gust event, it is crucial to consider the speed of the wind. Technical term abbreviations will be explained when first used. Many factors impact the speed of the wind, including the difference in air pressure. Conversely, wave height is mainly influenced by the wind's speed, direction, and duration. Statistical calculations were used to determine the average wind speed and wave height. The correlation between wind speed and wave height will be determined in a subsequent analysis.

Distribution analysis is conducted to identify the theoretical distribution that fits the actual data most accurately. This has been previously accomplished using the Kolmogorov-Smirnov and Chi-Square methods in past research. Both of these methods are frequently utilized for assessing the consistency of field data with the theoretical distribution [35]. The theoretical distribution is subsequently employed for determining the distribution of significant wave height. The fitting method for the probability density function uses three theoretical distributions; Normal, Lognormal, and Weibull. The annual maximum hourly significant wave height is analyzed, as well as wind speed [33], [34]. The study determines the theoretical distribution for both parameters and then establishes their relationship.

An extreme event analysis of the time series for wind speed and wave height was conducted. Knowing that wave height is predominantly influenced by wind, in terms of speed, direction, and duration, an extreme analysis is performed with the main focus on wave height rather than the other way around. The relationship between wind events before the extreme wave events was studied to determine correlations.

Results And Discussion

Wind and Wave Direction and Duration

Wind and wave direction at the Western of Lampung is shown in **Figure 2**. Wave direction is dominantly going to North to Northeast at all seasons. Wind direction is blowing from Southeast at Transition 1 and 2, and Southeast Monsoon seasons and Northwest at Northwest Monsoon. When the wind blows in a reversed direction from before, the wave direction is unaffected. In addition, it can also be seen that the direction of the wind and waves is not homogeneous.

Considering the location of Sumatra Island concerning this point, the direction of the waves tends to be perpendicular to the west coast of Sumatra. On the other hand, the wind speed at this point tends to be parallel to the west coast of Sumatra with the dominant maximum and average duration [34]. Wind and wave direction can also be seen in more detail in **Figure 3** over 6 months. Seasonal changes and variations in wind direction do not have an impact on wave direction in the area. This aligns with the theory of wave propagation, which states that waves travel from the deep sea to the shore perpendicular to the contours of the water.

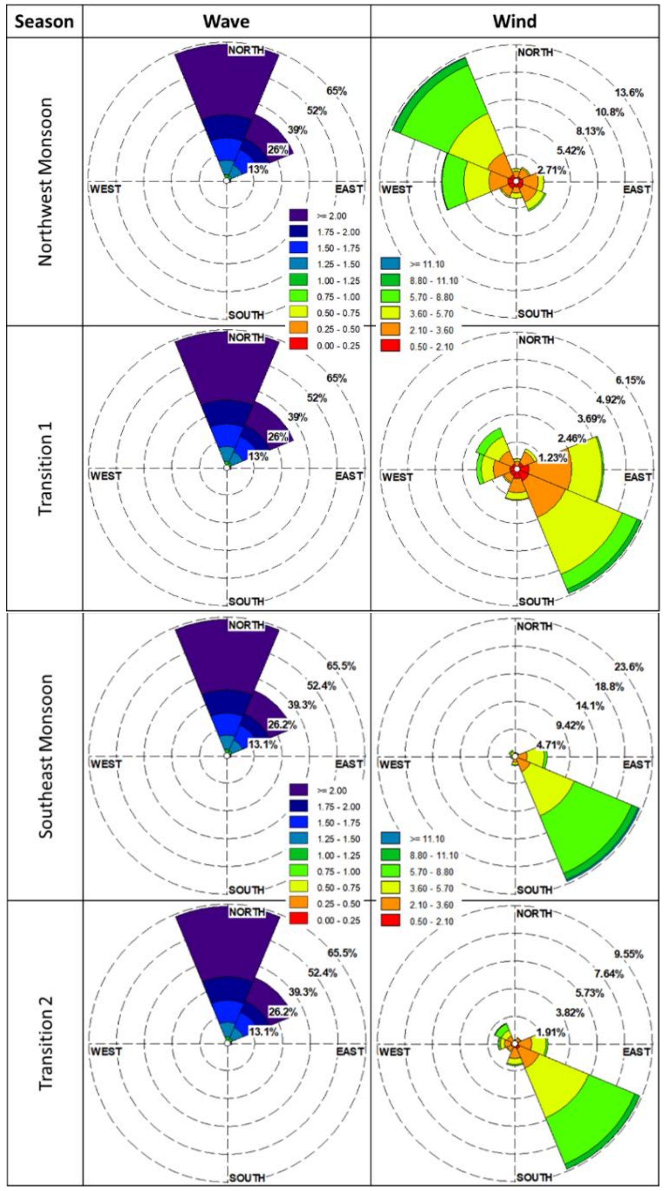

Figure 2. Windrose (blowing from) and waverose (going to) at point 1 [33], [34].

Whereas in the case of wind, the dominant influence is from air pressure, so it can change direction depending on the season. This finding diverges from prior research, which observed wind blowing from water toward land at the Southeast Sumenep [36]. The difference is believed to stem from the characteristics of the land and water areas. The Western Lampung coast is part of the west coast of Sumatra that stretches from Aceh to Lampung. It faces the Indian Ocean, while the southeastern waters of Sumenep face more limited waters and are restricted by numerous islands. This finding is in line with the X findings, which indicate that water from deep, colder waters moves toward the coast to generate longshore winds [37].

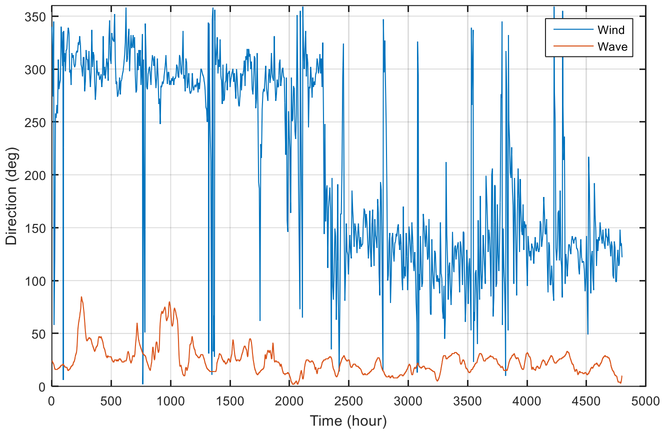

Figure 3. Wind (blowing from) and wave (going to) direction within a certain period at point 1.

Wind Speed and Significant Wave Height

The average wind speed is shown in **Figure 4** along with the average significant wave height shown in **Figure 5**. In this case, as it moves further to the southeast, the values for both average wind speeds are between 4-6 m/s and the average significant wave is between 0.25 – 2.25 meters. The relationship between wind speed and wave height at each point is shown in **Figure 6**.

Based on the figure below, it can be concluded that at every point in western Lampung, the greater the wind speed, the greater the wave height. The annual maximum wave height will be approximately a quarter of the annual maximum wind speed. Although the fit of the trendline of the relationship between wind speed and wave height is visually not very clear, it can be an approximate value.

Figure 7 shows the wave height and wind speed over 6 months. Based on the graph, the significant wave height per hour tends to fluctuate around the value of 2 meters. In contrast, the wind speed fluctuations are not between certain values or tend to be more random in this 6 months period that covers 2 seasons. However, upon closer examination, it appears that the wind speed is generally greater during the period preceding 2000 hours than during the next 2000 hours. The first 2000 hours is the period from January to March, which falls under the western season [38].

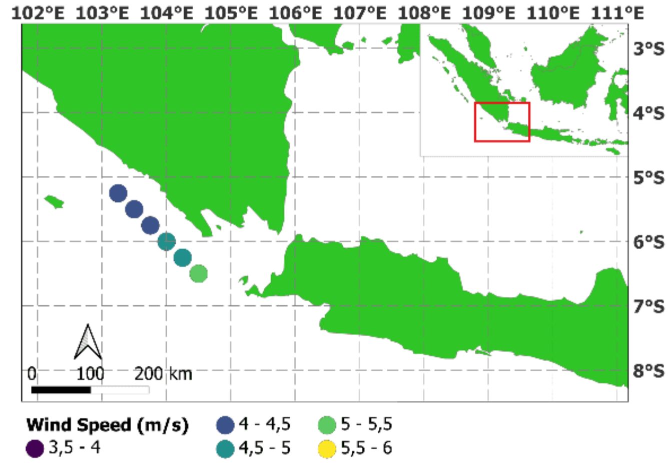

Figure 4. Average wind speed [34].

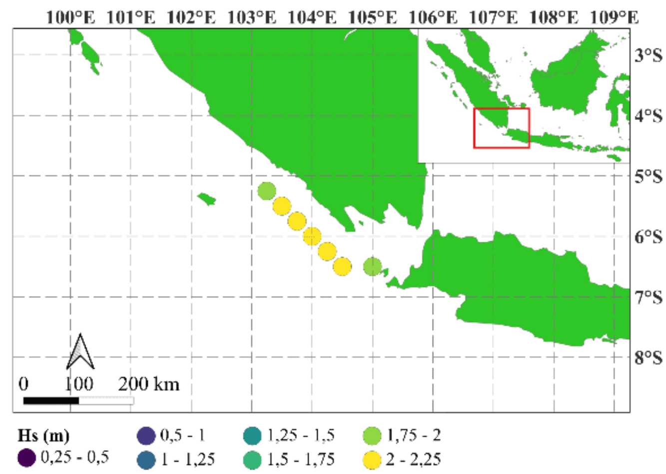

Figure 5. Average significant wave height [33].

Distribution Analysis

Figure 8 and **Figure 9** shows the wind speed and wave height distribution. This distribution is composed of annual maximum values for both wind speed and wave height (peak over threshold). The theoretical distributions used for fitting are Normal, Lof Normal, and Weibull. From the theoretical distribution fitting line, the Log Normal is best fit with the data distribution.

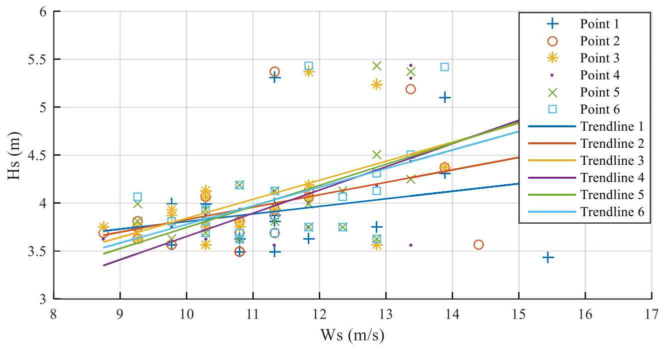

Figure 6. Average wind speed and significant wave height correlation at every point.

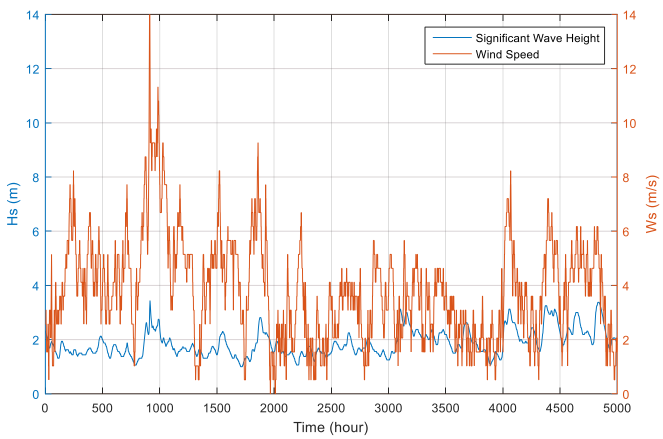

Figure 7. Wind speed and wave height in a certain period at point 1.

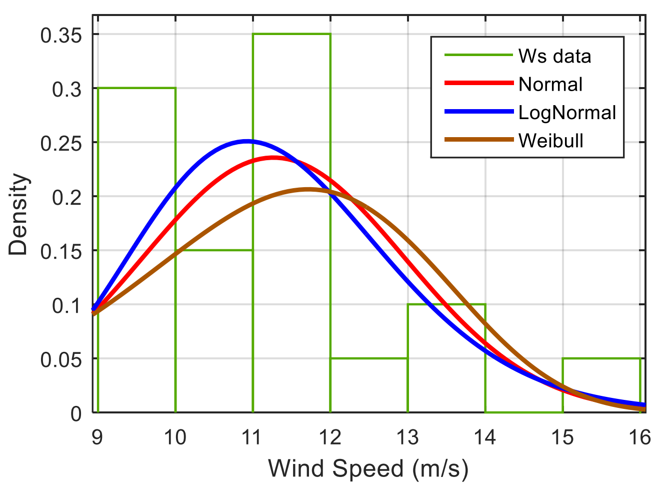

Figure 8. Wind speed distribution at point 1 [34].

Using the distribution fitting method of Kolmogorov-Smirnov (KS) and Chi-Square (CS), the distributions of wind speed and wave height data in western Lampung both best fit the Log Normal distribution. The average values of 0.109 for CS, 0.136 for KS of wind data, 0.18 for CS, and 0.21 for KS of wave data are below the error limit of 5.991 for CS and 0.304 for KS [33], [34]. This is different from that obtained in Chinese waters which is more suitable for the Weibull distribution [32]. The difference in the distribution of the corresponding waves is influenced by the density of opportunities in different regions which is related to the difference in geographical conditions and wave generation on the wave density formed [39].

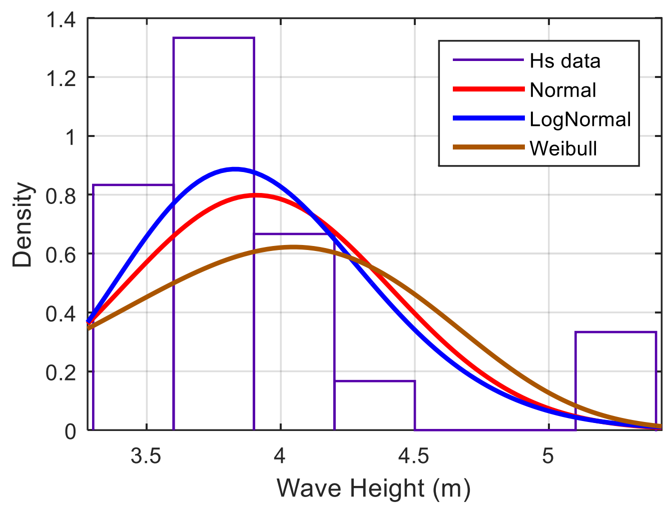

Figure 9. Wave height distribution at point 1 [33].

Extreme Event Analysis

Figure 10 shows one example of an extreme event, where the wave height at the reference point experienced the largest value in 20 years of data.

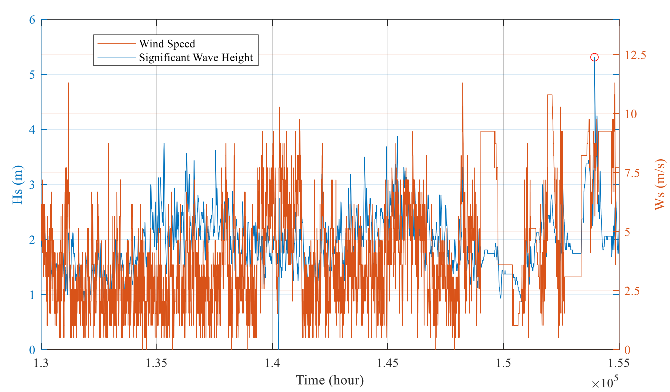

Figure 10. Wind speed and wave height in a certain period at an extreme event at point 1.

Based on the time series, it can be seen that continuously higher wind speeds result in higher wave heights. Some of the highest wind speeds occur before extreme wave events. This is in line with what was found in previous studies that only the top 10% of the highest wind speeds can cause extreme waves [30].

Conclusions

Wave direction is dominantly going to North to Northeast at all seasons. Wind direction is blowing from Southeast at Transition 1 and 2, and Southeast Monsoon seasons and Northwest at Northwest Monsoon. Average wind speed data range from 4 to 5.5m/s and average significant wave height 1.75 to 2.25m. At every point in western Lampung, the greater the wind speed, the greater the wave height. Furthermore, continuously high wind speeds over a long period result in higher wave heights.

Conflicts of interest

There are no conflicts to declare.

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