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Pesisir Barat Lampung Wave Characteristic Comparative Study

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Abstract

The need for ocean data is important to increase the utilization of ocean areas. A facility, development, system, or structure in the ocean cannot be planned properly without data in that ocean. One of the important data in water areas is ocean waves. In the offshore area of Pesisir Barat, wave characteristic data is still very hard to find. Knowledge of the ocean characteristics of the Pesisir Barat waters is needed, one of which is in the form of wave characteristics. To obtain more comprehensive information, two satellite reanalysis data sources were analyzed. The average height of significant wave height in the Perisir Barat is 1.75 to 2.25 m from BMKG and only 0.25 to 1.00 m from ECMWF. Based on the wave direction, the ocean waves in the Pesisir Barat move North to Northwest (NW), perpendicular to the coastline. The distribution of the annual maximum significant wave height matches the theoretical Log-normal distribution. Extreme significant wave height is obtained with a value of 4.10 to 4.29 m for a 100-year return period and 3.09 to 3.39 m for a 1-year return period. In terms of design or study of maritime potential in the western waters of Lampung, these values can be a benchmark as a basic study of wave characteristic data.

Keywords: Wave Characteristic, Significant Wave Height, Wave Distribution, Pesisir Barat

1. INTRODUCTION

Indonesia, the world's largest archipelago, spans approximately 8,205,961 square kilometers and comprises a total of 13,466 islands each with identified names and coordinates. With its vast water area surpassing its landmass, Indonesia's strategic geographical position enables significant control and utilization of the sea[1], [2]. As the largest archipelago, Indonesia has maritime potential. Therefore, maritime infrastructure focuses on development to make Indonesia the Global Maritime Nexus (GMN), which is in line with its five development pillars, namely prioritizing the development of maritime infrastructure and connectivity, with the development of Sea Tolls, Deep Seaports, Short Sea Shipping, Shipping Industry, and Maritime Tourism. In the development of infrastructure in a water area, it is essential to have accurate data about the waters. One of the most important types of data is the significant wave height of sea waves[3].This significant wave height is used in planning the design or engineering of onshore or offshore infrastructure, knowing and ensuring the safety and level of stability of the infrastructure built, and analyzing construction designs such as sea walls through accurate measurement and analysis [4], [5].
Significant wave height is very important in analyzing a phenomenon or problem, for example, it can be used in analysis related to wave climate[6], wave-current interaction with or without structure[7], ship reliability assessment[8], impact on offshore structures, and coastal impact assessment[9]. Therefore, the need for wave height data in a studied water area is very important. The inaccuracy of the data used in the analysis can be fatal in design calculations [10].
Significant wave height data can be obtained from several sources, either from government agencies or abroad and based on survey results or data reanalysis. There are also free and paid data [11]. To obtain more comprehensive information, at least two data sources were analyzed. Data sourced from government institutions are BMKG significant wave height data and data sourced from foreign agencies such as ECMWF significant wave height data, where both data are included in satellite reanalysis data [2], [12].

Lampung Province is a province located on the island of Sumatra which is located at the southern tip and directly borders Java Island. Its strategic location is an opportunity and potential for the development of the marine industry with a seawater area of 24,820 km and 132 large and small islands. Lampung Province has a coastline of 1,105 km which is the second longest in Sumatra Island after Nanggroe Aceh Darussalam Province. The oceanographic conditions of Lampung Province waters differ from one region to another. Lampung Province has 3 types of waters, namely East Coast Waters in the shallow sea, West Coast Waters facing the open ocean, and Gulf Waters. For waters facing the open sea, namely the West Lampung Waters, the influence of the season and wind waves is very dominant because it is directly adjacent to the ocean. However, in the western region of Lampung province, specificly in Pesisir Barat Regency, data on wave characteristics are still very minimal. Therefore, it is necessary to know the environmental characteristics in the western waters of Lampung, one of which is in the form of wave characteristics so that its potential can be mapped properly and can be a reference in sustainable development [6], [13], [14].

2. METHODS

2.1. Statistical Distribution

Wave height data statistics were analyzed in this study. The main parameter used in this study is the significant wave height at each point analyzed, so a data distribution is needed. The distribution of significant wave height is based on theoretical distribution. The fitting process uses 3 theoretical distributions for the probability density function including Normal, Lognormal, and Weibull [15], [16]. The distributions that will be analyzed are suitable and can be used in the characteristics of ocean waves off the Pesisir Barat Lampung. The analysis includes the annual maximum wave height, the same value, and the average significant wave height [16]. The resulting data can be analyzed to determine wave characteristics in the Pesisir Barat Lampung waters.

2.2. Probability Density Function

The probability density function is shown in equations (1) for Normal distribution, (2) for Log normal distribution, and (3) for Weibull distribution. Each parameter for Lognormal and Weibull is described in equation (4) to (7) [8], [17].

$$f_{normal}(x) = \frac{1}{\sigma_X\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu_X}{\sigma_X}\right)^2\right] \tag{1}$$

$$f_{lognormal}(x) = \frac{1}{\sqrt{2\pi}\zeta_X x}\exp\left[-\frac{1}{2}\left(\frac{\ln x-\lambda_X}{\zeta_X}\right)^2\right] \tag{2}$$

$$f_{weibull}(y_1) = \frac{k}{w_1}\left(\frac{y_1}{w_1}\right)^{k-1}\exp\left[-\left(\frac{y_1}{w_1}\right)^k\right] \tag{3}$$

$$\lambda_X = \ln\mu_x - \frac{1}{2}\zeta_X{}^2 \tag{4}$$

$$\zeta_X{}^2 = \ln\left(1+\delta_x{}^2\right) \tag{5}$$

$$k = \delta_{Y_1}^{-1.08} \tag{6}$$

$$w_1 = \frac{\mu_{Y_1}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{7}$$

2.3. Distribution Fitting

The distribution fitting methods used in this research are Kolmogorov-Smirnov and Chi-Square. The Kolmogorov-Smirnov (KS) test is used to evaluate the agreement between the distribution of a random sample {X1, . . . , Xn} and a theoretical [18], [19]. It is defined as result value calculated using equation (8).

$$D_n = \max|F_X(x_i) - S_n(x_i)| \tag{8}$$

Whereas, the Chi-Square method uses the probability density function described above. Chi-Square result value is calculated using equation (9).

$$\sum_{i=1}^{m} \frac{(n_i - e_i)^2}{e_i} \tag{9}$$

where n_i is frequency of observation, e_i is expected frequency based on an assumed model distribution, for category of type i, and m is the number of categories. Both n_i and e_i are unitless. ν =m – p –1 is the number of degrees of freedom, where p is number of parameters of the model distribution calculated from the data[20], [21].

2.4. Extreme Value

Extreme value is calculated depending on the best-fit distribution to the data. An extreme value in a set of observations refers to an exceptionally large or small value. These values, often known as outliers, represent the highest and lowest points in the data series [22], [23]. Equation (10) gives the general equation that determines the extreme value.

$$P(X > Ws_n) = \frac{1}{RP} \tag{10}$$

3. RESULTS AND DISCUSSION

3.1. Pesisir Barat Wave Characteristic

3.1.1. Waverose

Wave Rose (Waverose) is a method of depicting information regarding the frequency of events in each direction of the eye wind and wave height classes at the specified location and time in one centimeter (cm) or meter (m) [7], [24]. Figure 1 and Figure 2 show the waverose for each season in Indonesia, where on the left is BMKG data and on the right is ECMWF data.

The wind blows for each season in Indonesia are shown in the figure above. The wind blows predominantly to the north in the East Monsoon, Transition Season 1, and Transition 2 both BMKG and ECMWF data. In contrast, in the West Monsoon, the wind blows predominantly to the northeast and north in ECMWF data and predominantly to the north in BMKG data. With a wave height range of 0 m – 2 m, the percentage of occurrence of each wave height class has a significant difference between the BMKG and ECMWF data. This means that the two data sources have a high similarity in terms of hourly wave direction but are quite different in terms of wave height [25]. The northwest monsoon season covers December to March. Transitional season 1 covers the months of April to May. The southeast monsoon season covers June to September. Transitional season 2 covers October to November [26][27].

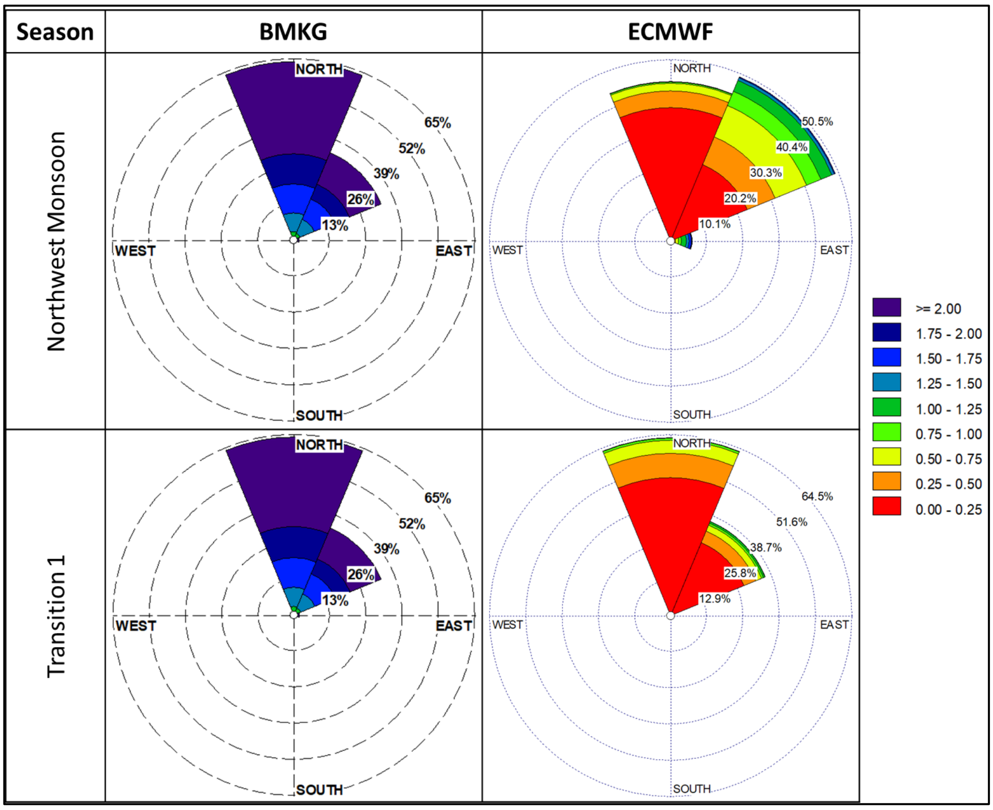

Figure 1. Windrose for Northwest Monsoon and Transition 1 season.

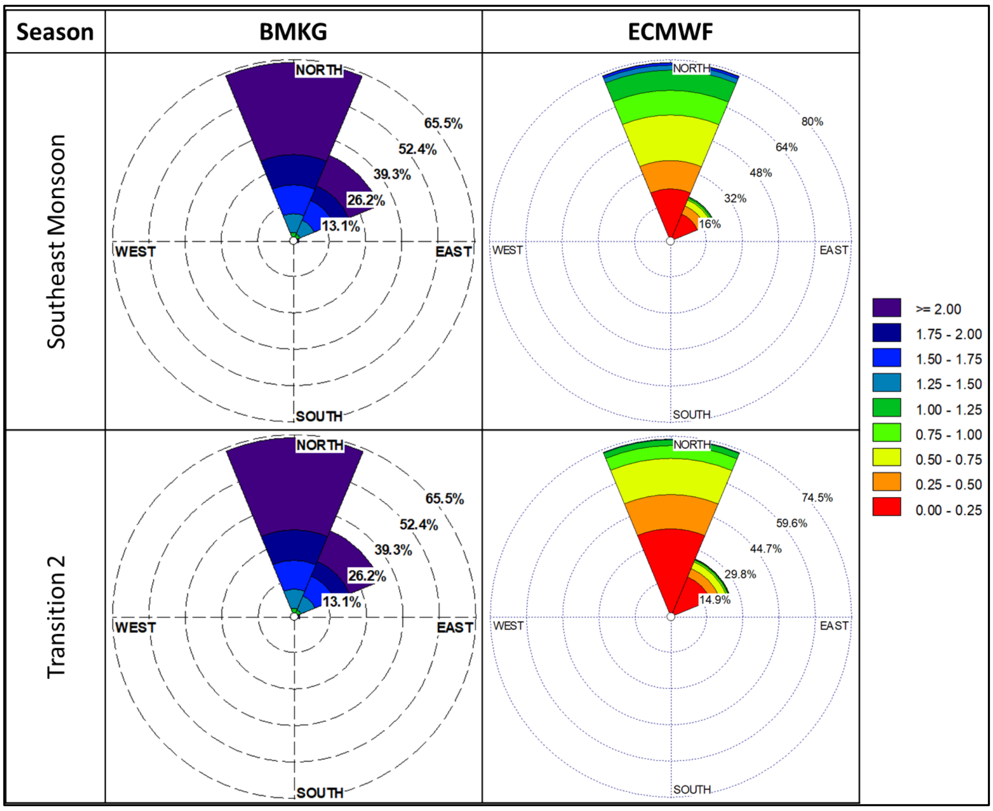

Figure 2. Windrose for Southeast Monsoon and Transition 2 season.

3.1.2. Significant Wave Height

The average significant wave height map for BMKG and ECMWF data is shown in Figure 3 below, the left image is for BMKG data and the right is for ECMWF data.

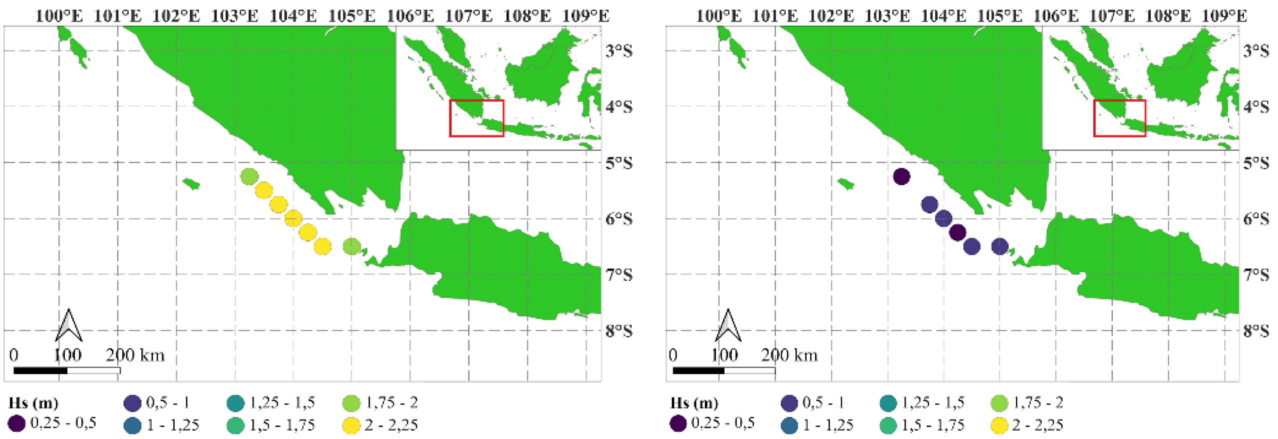

Figure 3. Average Significant Wave Height for BMKG (left) and ECMWF (right).

The BMKG average significant wave height data ranges from 1.75 to 2.25 meters, with the highest average wind speeds occurring in the southeast direction. ECMWF's average significant wave height data ranges from 0.25 to 1.00 meters, following the same pattern as BMKG's data. However, there is a data gap at point 2.3 in the ECMWF data, indicating a limitation as ECMWF data is not available at all points in this area.

3.1.3. Wave Height and Period Relation

Fetch, the distance the wind travels across the surface of the water, influences the height and period of the waves generated. A longer fetch results in higher wave heights and longer wave periods. Consequently, as the return period increases, the sea wave height also increases. [28]. Figure. 4 below illustrates the distribution data showing the relationship between wave height and wave period.

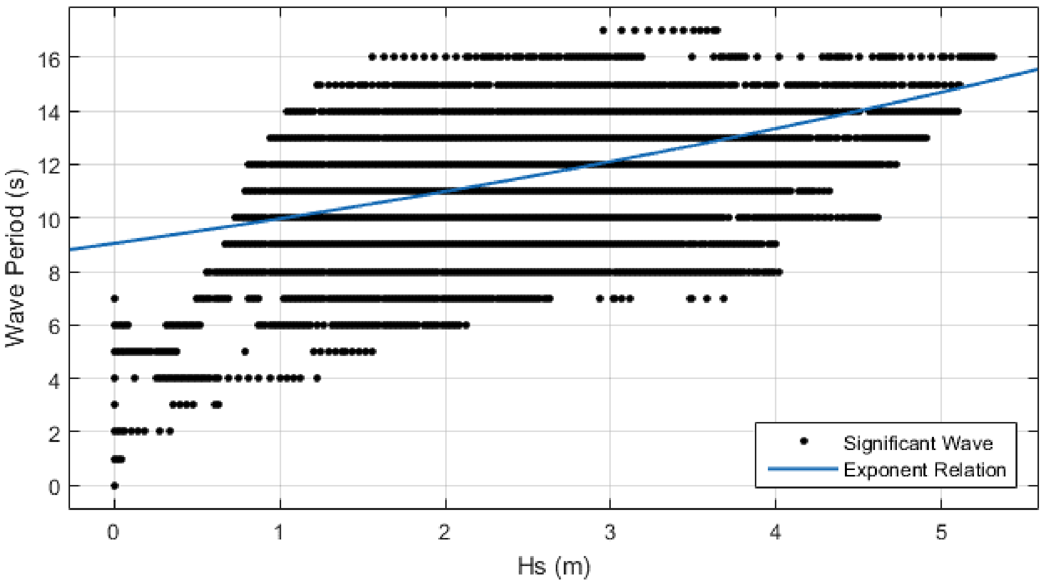

Figure. 4. Wave Height and Period Relation.

Based on the results of the scatter data obtained, the relation of wave height and wave periods is shown in equation (11). An increase in wave height will increase the value of the wave period in the exponent relationship [29], [30].

$$T = 10.96e^{0.05637 \cdot H_s} \tag{11}$$

Description:

- T = Wave Period (s),
- H_s = Significant Wave Height (m).

3.1.4. Annual and Seasonal Data

The annual maximum wave heights for observed point 1.1 are shown in Figure. 5 for BMKG data and Figure. 6 for ECMWF data. Meanwhile, Figure. 7 shows the seasonal maximum wave height for BMKG data on the left and ECMWF data on the right for point 1.1.

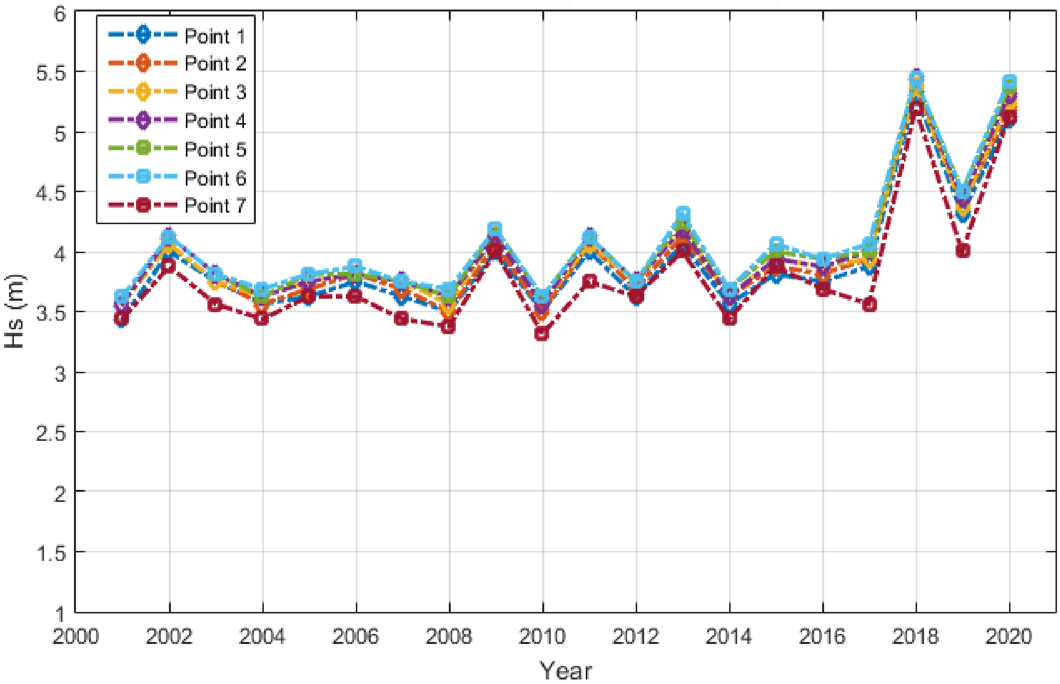

Figure. 5. Annual Maximum Significant Wave Height for BMKG.

The results show that the annual maximum wave height distribution of BMKG data looks more uniform for all points. In the distribution of BMKG and ECMWF data, point 7 has the smallest annual maximum data among all points. Meanwhile, the largest annual maximum data is at point 6 for BMKG and ECMWF data. The largest seasonal maximum wave height in BMKG and ECMWF data occurs in the 2018 Southeast Monsoon. The smallest seasonal maximum wave height in BMKG data occurs in Transitional Season 2 while ECMWF data occurs in Transitional Season 1. Seasonal maximum wave height is used in understanding the characteristics of waves in an area, as a basis for planning coastal protection buildings. While the annual maximum wave height in understanding the potential form of the impact of individual waves on mariner navigation and coastal erosion[31], [32].

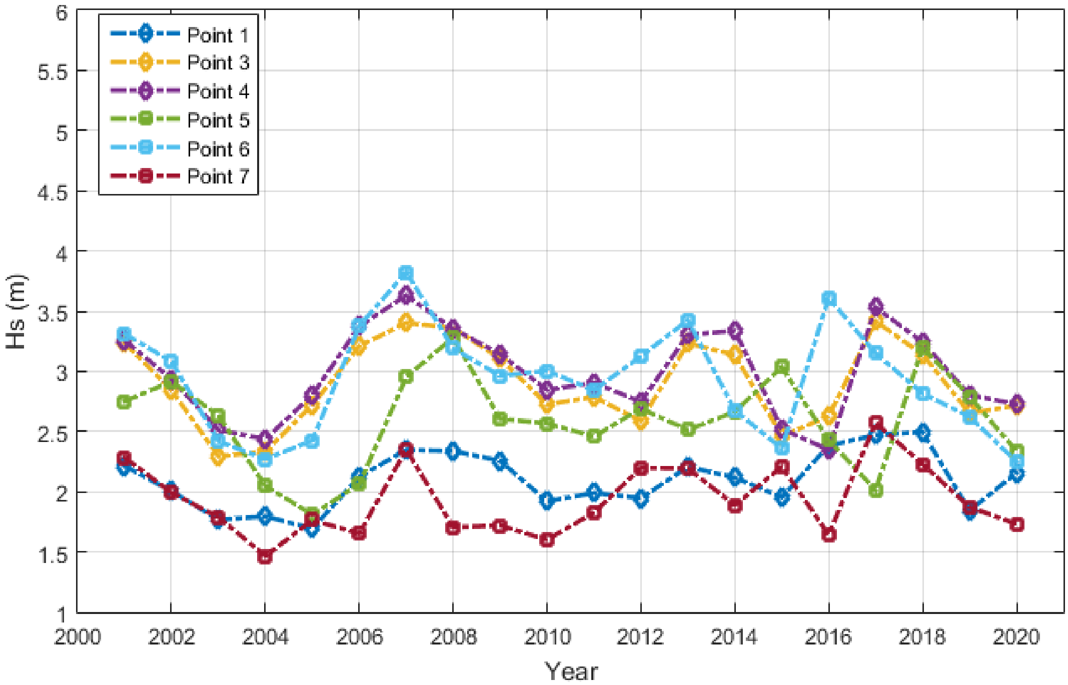

Figure. 6. Annual Maximum Significant Wave Height for ECMWF.

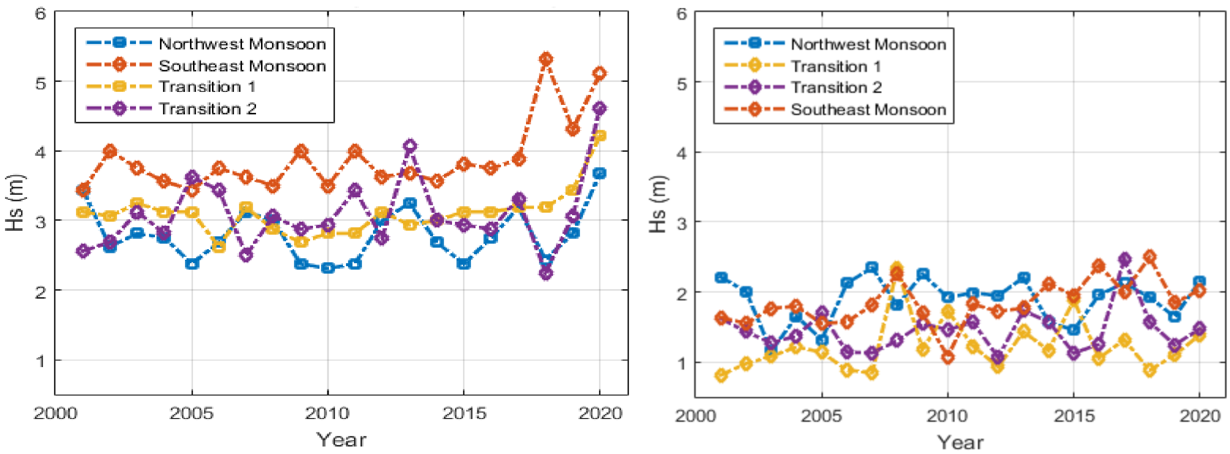

Figure. 7. Seasonal Maximum Significant Wave Height of Point 1 for BMKG (left) and ECMWF (right).

3.1.5. Data Distribution

Figure. 8 below is a visualization of the data histogram and distribution of significant wave height. The left image is for BMKG data and on the right is ECMWF data.

The ECMWF data ranges from 1.69 to 2.49 meters, whereas the BMKG data shows wave heights between 3.43 and 5.31 meters, indicating that BMKG values are higher than ECMWF values. Visualization results suggest that the Log-Normal distribution best fits the significant wave height data. A goodness-of-fit analysis was performed to determine the most suitable distribution. Table 1 presents the Kolmogorov-Smirnov values, and Table 2 displays the Chi-Square values for both datasets.

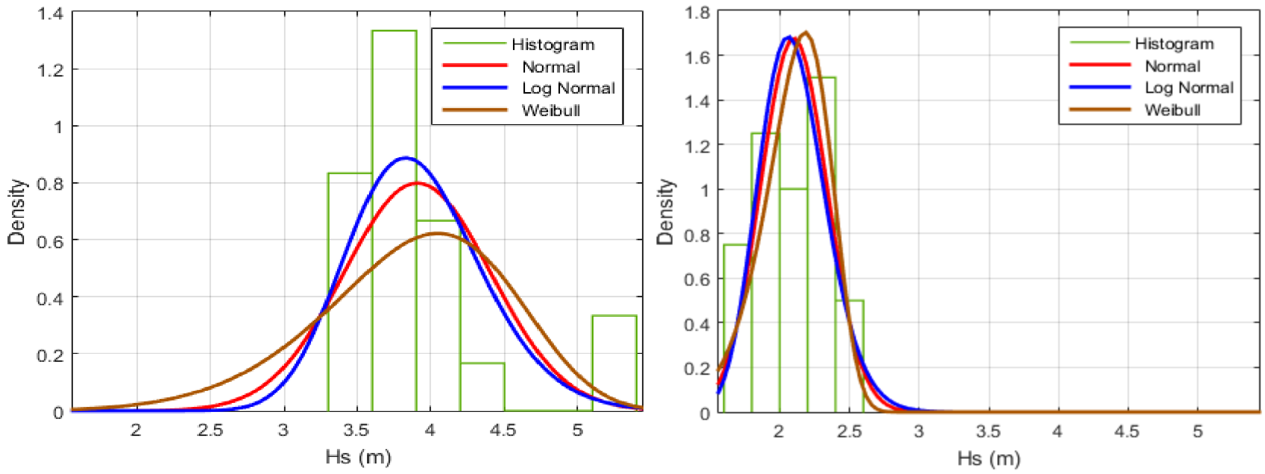

Figure. 8. Data Theoretical Distribution Fitting for BMKG (left) and ECMWF (right).

Table 1. Kolmogorov-Smirnov Analyses Value.

		Kolmogorov-Smirnov Value per Point						
Data	Dist.	1	2	3	4	5	6	7
BMKG	Normal	0.199	0.173	0.212	0.228	0.276	0.212	0.223
	Log-Normal	0.191	0.174	0.203	0.217	0.266	0.204	0.222
	Weibull	0.223	0.190	0.248	0.275	0.315	0.247	0.257
ECMWF	Normal	0.137	-	0.143	0.161	0.148	0.159	0.234
	Log-Normal	0.136	-	0.165	0.139	0.168	0.166	0.208
	Weibull	0.175	-	0.181	0.196	0.151	0.146	0.261

Table 2. Chi-Square Analyses Value.

		Chi-Square Value per Point						
Data	Dist.	1	2	3	4	5	6	7
BMKG	Normal	0.627	0.310	0.102	0.231	0.006	0.103	0.176
	Log-Normal	0.536	0.243	0.140	0.174	0.003	0.074	0.120
	Weibull	0.156	0.673	1.354	0.550	0.083	1.330	0.450
ECMWF	Normal	0.436	-	0.685	0.141	0.490	0.146	0.859
	Log-Normal	0.278	-	0.446	0.153	0.823	0.318	0.222
	Weibull	0.885	-	0.132	0.383	0.245	0.069	1.170

Log-Normal distribution obtained the most matching distribution results with the lowest error value found on BMKG and ECMWF data with averages at all points respectively of 0.21 and 0.16 for Kolmogorov-Smirnov and 0.18 and 0.37 for Chi-Square. Whereas Weibull data processed the distribution result with the highest error values found on both BMKG and ECMWF with averaging values at all respective points of 0.25 and 0.19 for Kolmagorov-Smirnov, and 0.66 and 0.48 for Chi-Square. With the limit of the value of Kolmogorov-Smirnov of 0.304 and a value of Chi-Square of 5.991, the whole result does not exceed that limit.

3.1.6. Extreme Value

Extreme value wave height is calculated for 1-year and 100-year return periods for each data can be seen in Figure. 9 and Figure. 10.

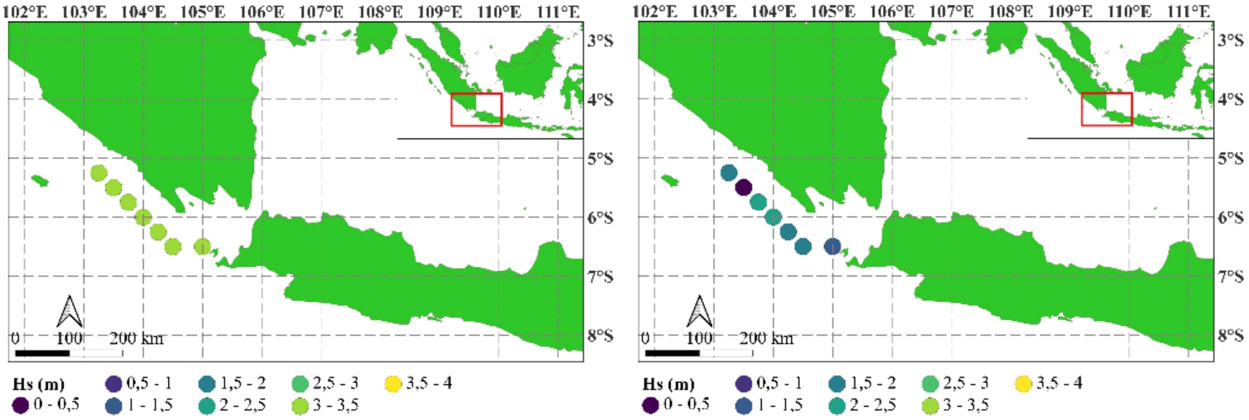

Figure. 9. 1-year extreme wave height for BMKG (left) and ECMWF (right).

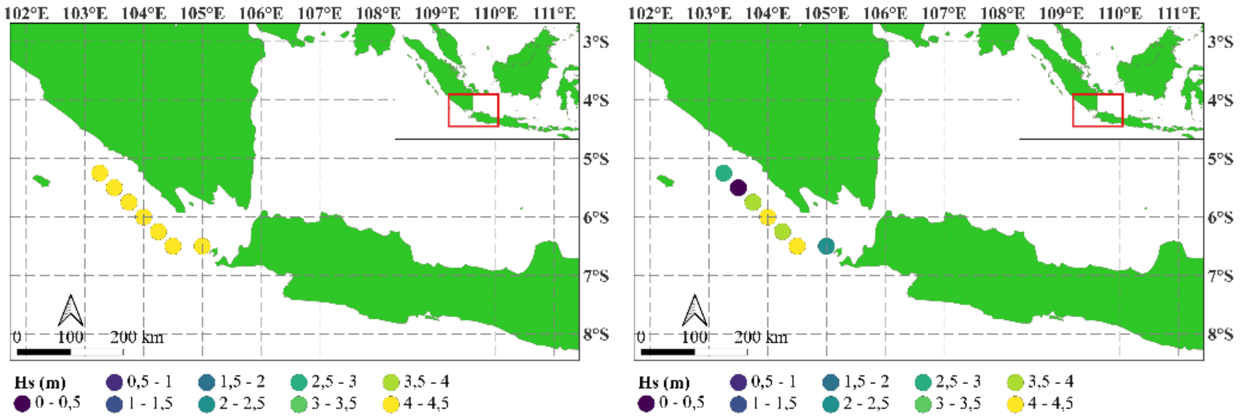

Figure. 10. 100-year extreme wave height for BMKG (left) and ECMWF (right).

Extreme values of significant wave height were calculated for return periods of 1 year and 100 years for each dataset. Figures 9 and 10 present the results for the 1-year and 100-year return periods, respectively. The findings indicate that the values are not significantly different from the previous average significant wave height data. BMKG results show larger extreme wave heights compared to ECMWF results for both return periods. For the 100-year return period, BMKG results range from 4.10 to 4.29 meters at all points, whereas ECMWF results range from 2.39 to 4.24 meters. This difference is visually apparent in the extreme wave height maps, with BMKG's map displaying an overall brighter color than ECMWF's map. BMKG results are 40.47% higher than ECMWF results for the 100-year return period. Similarly, for the 1-year return period, BMKG results range from 3.09 to 3.39 meters, while ECMWF results range from 1.31 to 2.20 meters. BMKG results are 114.22% higher than ECMWF results for the 1-year return period. These significantly higher wave height values are crucial for determining the probability of extreme wave occurrences over specific periods, contributing to the understanding of wave characteristics in Pesisir Barat [9], [33].

4. CONCLUSION

For all data sources and points analyzed, wave dominantly going to North to Northeast with an average significant wave height of 1.75 to 2.25 m from BMKG and only 0.25 to 1.00 m from ECMWF. Southeast monsoon season is the most critical season with the highest wave height in contrast to northwest monsoon season for BMKG and Transition 1 season for ECMWF. Both data distributions are best fitted with the theoretical log-normal distribution. From that, BMKG's extremely significant wave height is obtained with a value of 4.10 to 4.29 m for a 100-year return period and 3.09 to 3.39 m for a 1-year return period. In terms of the design or study of maritime potential in the western waters of Lampung, these values can be a benchmark as a basic study of wave characteristic data. This extreme value of significant wave height can be used for further planning the design or engineering of onshore or offshore infrastructure in the Pesisir Barat. Not only that, knowing and ensuring the safety and level of stability of the infrastructure built, and analyzing construction designs through this data using this data will make accurate results.

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