Original Research Article

STUDY OF MAXIMUM AVERAGE WAVE HEIGHT DISTRIBUTION IN THE SOUTHERN WATERS OF JAVA ISLAND DURING THE PERIOD 2010-2021

ABSTRACT

Aims: To determine the distribution of maximum average wave height in the southern waters of Java Island and to identify the time and season when the maximum average wave height occurs.
Study design: Analyzing the map of the distribution of maximum average wave height in the southern waters of Java Island.
Location and Duration: Department of Physics, Udayana University, and BMKG TunggulWulung Meteorology Station Cilacap, between January 2023 and February 2023.
Methodology: Daily maximum wave height data in the southern waters of Java Island from January 2010 to December 2021 at 00.00, 06.00, 12.00, and 18.00 UTC, with a latitude coordinate limit of 7° LS to 12° LS and longitude of 106° BT to 112° BT. The data was calculated using Microsoft Excel and grouped by season and time. The maximum average wave height data was then plotted using Surfer software, and the result is a map of the distribution of maximum average wave height.
Results: The highest maximum wave height was found in the southern Indian Ocean from West Java to East Java. The highest maximum wave height in the waters of Sukabumi-Garut, West Java, and the lowest in the waters of Pangandaran-Yogyakarta. The maximum average wave height tends to be high in the morning at 18.00 UTC for the Perlihan I, Timuran, and Peralihan II wind seasons. Meanwhile, during the Baratan wind season, the maximum wave height tends to be high at 12.00 UTC. The highest maximum average wave height occurred during the Timuran wind season.
Conclusion: The map of the distribution of maximum average wave height can be used as a consideration for predicting the maximum wave height in the southern waters of Java Island.

Keywords: Baratan wind season, maximum wave height, Surfer, southern waters of Java Island, Timuran wind season

1. INTRODUCTION

Indonesia is one of the world's largest archipelagic countries with a total of 17,499 islands stretching from Sabang to Merauke. Indonesia is also a maritime country, with its waters covering 5.8 million km^2, including 3.25 million $km^2$of the ocean and 2.55 million km^2 of the Exclusive Economic Zone [15]. Java Island is a densely populated island with a population of around 154.34 million people [10]. This island is inhabited by people from urban areas to coastal areas, with the majority of the coastal population being fishermen.

One of the natural conditions that fishermen are unaware of is the incoming wave height. Sea waves are one of the factors that affect coastal dynamics processes [21]. The height of sea waves is essential for the safety of fishermen and all activities at sea. From a climatological perspective, Indonesia is influenced by the west monsoon wind and the east monsoon wind, which affect the sea wave every month.

The purpose of this study is to determine the distribution of maximum average wave height in the southern waters of Java Island and to identify the time and season when the maximum average wave height occurs

1.1 Overview of Java Island

Java Island is one of the largest and most densely populated islands in Indonesia, with an area of approximately 128,297 km^2. Astronomically, Java Island is located at 7º30'10" S, 111º15'47" E. It borders Sumatra Island to the west, Bali Island to the east, Kalimantan Island to the north, and Natal Island to the south. Java Island is surrounded by several bodies of water, including the Indian Ocean to the south, Bali Strait to the east, Sunda Strait to the west, and Java Sea to the north [16].

The island is surrounded by different seas, each with distinct characteristics. The waters on the northern side have a relatively flat sea floor, resulting in smaller waves, while the waters on the southern side have a steeper topography, resulting in larger waves. Furthermore, the southern waters directly border the Indian Ocean [22].

1.2 Sea Waves

The ocean is a vast source of energy in the form of waves generated by both wind and tides. The potential types of sea waves that can be used for energy are wind waves and tidal waves. Wind waves are created by wind blowing across the ocean's surface, transferring energy from the wind to the water. Tidal waves, on the other hand, are caused by the gravitational pull of celestial bodies, mainly the moon and the sun, on the Earth's oceans [17]. Wave height is measured by comparing the height of the water at the crest and trough of the wave using a wave staff. The difference between the crest and trough is the wave height [6].

1.3 Monsoon Winds

Monsoon winds are periodic winds that blow for a minimum of three months, with each period reversing direction every six months. The West monsoon winds blow from Asia towards Australia, occurring from December to February, while the East monsoon winds blow from Australia towards Asia, occurring from June to August [4].

1.4 The Relationship Between Monsoon Winds and Sea Waves

According to McPhaden and Hayes (1991), wind movements can affect the characteristics of water masses in the ocean, including changes in surface current direction. Strong wind movements can cause water masses in the upper layers to mix, resulting in a homogenous temperature throughout the region. The World Meteorological Organization (WMO) (2001) identifies three types of waves in the ocean, based on their causes or restoring forces. These are wind-generated waves, tsunami waves caused by earthquakes, and tidal waves caused by the gravitational pull of celestial bodies. Of these, wind-generated waves are the most frequent and dominant type. The Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) considers wind speed and wave height to be critical weather factors to be taken into account for maritime safety. For passenger ships, sea states with a wind speed of over 21 knots and wave heights above 2.5 meters are considered high-risk conditions. Such weather conditions are included in the WMO Sea State Code's high wave warning (BMKG).

1.5 ODV

Ocean Data View (ODV) is a software for interactive exploration, analysis, and visualization of oceanography and other geo-referenced profile data, time series, tracks, or sequential data. ODV runs on Windows, Mac OS X, Linux, and UNIX (Solaris, Irix, AIX) systems. ODV data and configuration files are platform-independent and can be exchanged between different systems [13].

1.6 Surfer

Surfer is a software used for contour mapping and three-dimensional modeling based on grids. The software plots irregular XYZ tabular data into regular quadrilateral points (grid). The grid is a series of vertical and horizontal lines in the Surfer software in the shape of quadrilaterals used as the basis for forming contours and three-dimensional surfaces [3].

1.7 Statistics [comment: statistics specific to this study should be defined / addressed below, rather than general concepts]

Statistics is a collection of methods and rules related to the collection, processing (analysis), drawing conclusions from numerical data using certain assumptions [7].

The statistical calculation used in this study is the mean. The mean is the result of dividing the sum of scores by the number of respondents. Mean calculation is a simple calculation because it only requires the sum of scores and the number of respondents (n). Mean is only used for interval or ratio data. For scores that are in the form of groups, the median value of the group is used to calculate the mean [7].[comment: were scores / median values applied in your data?]

The calculation of the mean is done by adding up all the data values of a sample group, then dividing it by the number of samples, then the mean of the sample can be calculated with Equation (1) [19].

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + \cdots + x_n) \quad (1)$$

Explanation :

$\bar{x}$ = aritmethic mean

x_n= The value of the n-th sample.

n =The total of samples

2. MATERIALS AND METHODS

The location that is the object of the study is the waters south of Java Island[comment: please rewording] with a latitude coordinate range of 7 ºS to 12 ºS and longitude 106ºE to 112 ºE. The location map of the study is shown in Figure 1.

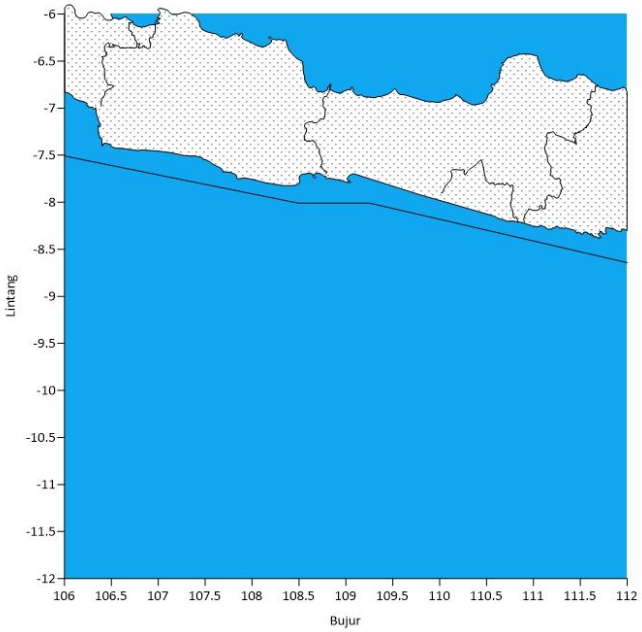

Figure 1. Map of research locations.

2.1 Data Collection Method

1. Maximum Wave Height Data in the South Java Waters

Maximum wave height data is reanalysis data obtained by downloading through the Copernicus website (with a resolution of 0.250 x 0.250 in Network Common Data Form (NetCDF) format). The data used is daily maximum wave height data every six hours[comment: please explain 'daily' vs 'every 6 hours'] for the period from January 2010 to December 2021 with a geographical boundary of 106ºE in the west and 112ºE in the east, as well as 7 ºS in the north and 12ºS in the south.

2. Wind Season Data in the South Java Waters

Wind season data, including the Westerly season, the First Transition season, the Easterly season, and the Second Transition season, is used to determine the period of the maximum wave height season. The First Transition season is the transition season from the Westerly to the Easterly season. The Second Transition season in this study is the

transition season from the Easterly to the Westerly season, while the Easterly Wind occurs in June, July, and August, and the Westerly Wind occurs in December, January, and February [18].

2.2 Data Processing Method

The maximum wave height data obtained from NetCDF format downloaded were extracted using Ocean Data View (ODV) software, which resulted in Comma Separated Values (CSV) format. Next, the data in CSV format was opened using Microsoft Excel which resulted in data tables including date, month, year, time, geographic coordinates of longitude and latitude, and maximum wave height (Hmax).[Comment: what kind of maximum wave height? Daily or 6-hourly]

The maximum wave height data was grouped based on coordinates, month, and time, and then averaged according to their respective time and season. The average maximum wave height data was then plotted using Surfer software, resulting in a map of maximum wave height every six hours at 00.00, 06.00, 12.00, and 18.00 UTC in the waters south of Java Island. [Comment: looks like 6-hourly. Right?]

2.3 Analysis Method

The data analysis process used a descriptive analysis method which described the data in the form of a map of maximum wave height to determine the time, wind season, and location or area in the waters south of Java Island where the maximum wave height occurred. In determining the maritime region, the criteria set by the Meteorology, Climatology, and Geophysics Agency (BMKG) were used, as shown in Table 1.

Table 1 Maritime Region and Southern Ocean of Java Island

No	Region	Province
1.	Sukabumi-Cianjur Waters	West Java
2.	Garut-Pangandaran Waters	West Java
3.	Cilacap Waters	Central Java
4.	Kebumen-Purworejo Waters	Central Java
5.	Yogyakarta Waters	Yogyakarta
6.	Southern Waters of East Java	East Java
7.	South Indian Ocean West Java	West Java
8.	South Indian Ocean Central Java	Central Java
9.	South Indian Ocean East Java	East Java

The map of the maritime region and Southern Ocean of Java Island based on BMKG maritime information is shown in Figure 2.

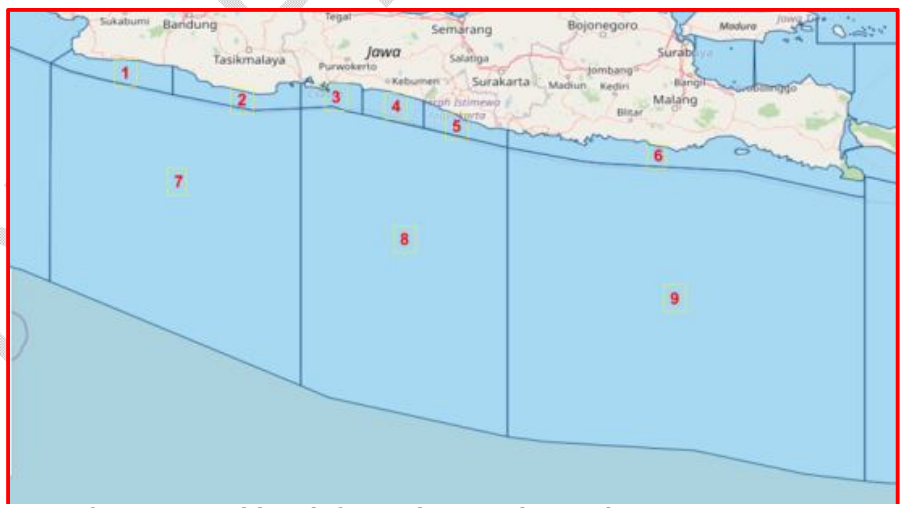

Figure 2. Map of BMKG maritime information service region
(https://peta-maritim.bmkg.go.id/area/pelayanan/)

2.4 Framework of Thought

The following is the framework of thought for all activities that will be carried out in the processing of average maximum wave height data[comment: what kind of average – by time or by region/area.. how?] in the waters south of Java Island for the period from 2010 to 2021. The research flow diagram is shown in Figure 3.

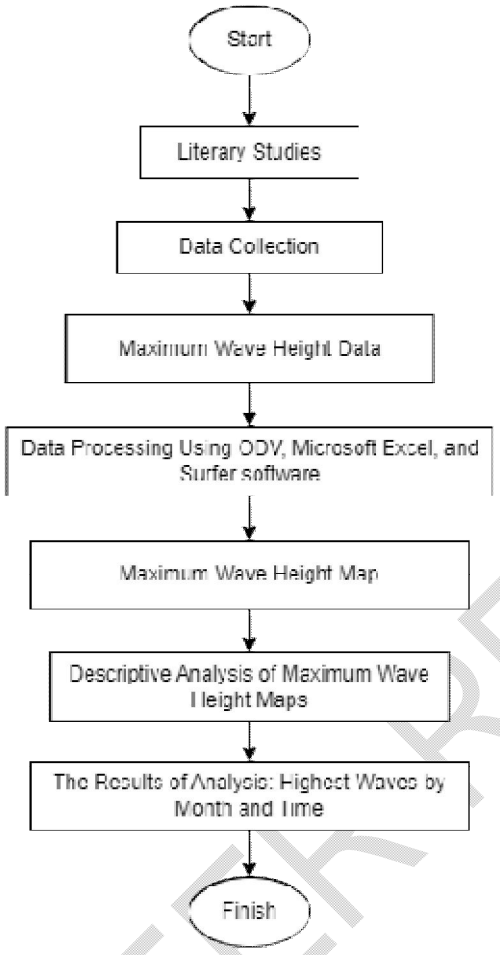

Figure 3. Research flow diagram

3. DATA AND RESULTS DISCUSSION

3.1 Wave Height Data

After extraction using ODV software, the maximum height data were calculated using Microsoft Excel, resulting in 143 coordinate points. At each coordinate point, calculations were made to obtain the average every six hours at 00.00, 06.00, 12.00, and 18.00 UTC for each month[comments: please clarify this 'average'] from January to December during the period from 2010 to 2021. Furthermore, the average maximum wave height was calculated for each season, namely the Westerly, Transition I, Easterly, and Transition II seasons. The results of the maximum wave height calculations for the Westerly season are shown in Table 2, and for the Transition I, Easterly, and Transition II seasons, see Appendices 1 to 4.

Table 2. Average maximum wave height during the West Wind season from 2010-2021 [comment: 12-year average?]

Average maximum wave height during the West Wind season(m)					
Longitude (ºBT)	Latitude (ºLS)	00.00 UTC	06.00 UTC	12.00 UTC	18.00 UTC
106	-12	3.616665	3.606699	3.612597	3.605437
106.5	-12	3.618565	3.607625	3.613082	3.605422
107	-12	3.62363	3.610554	3.617449	3.607938
107.5	-12	3.630032	3.615374	3.622421	3.612066
108	-12	3.636495	3.62149	3.628055	3.616571
108.5	-12	3.641702	3.627584	3.63412	3.622278
109	-12	3.645439	3.632563	3.639403	3.626744

109.5	-12	3.64743	3.636063	3.643857	3.629521
110	-12	3.647181	3.638445	3.646058	3.631099
110.5	-12	3.644736	3.639047	3.64718	3.631534
111	-12	3.638914	3.637305	3.645795	3.629284
111.5	-12	3.633091	3.633944	3.641567	3.625781

3.2 Maximum Wave Height Map

The Surfer software generated maps showing the distribution of maximum wave height for each season, including the Westerly Wind, Easterly Wind, Transition I, and Transition II seasons every six hours.

3.2.1 West Wind Season

The map of the maximum wave height distribution during the West Wind season is shown in Figure 4.

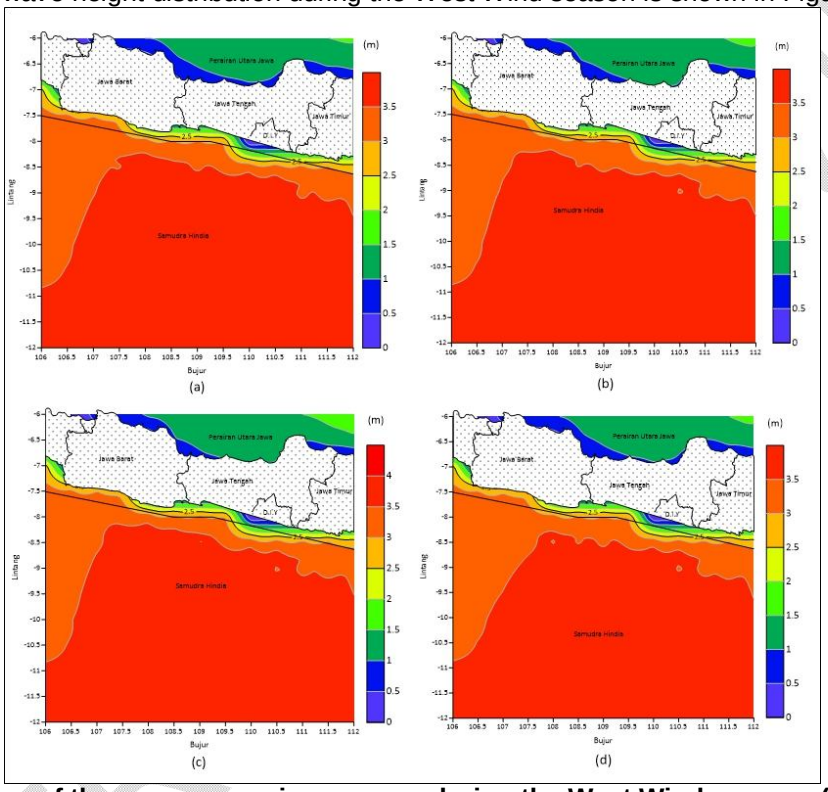

Figure 4. Distribution map of the average maximum wave during the West Wind season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC.

Based on Figure 4, it is shown that during the West Wind season from 00.00 to 18.00 UTC, the highest maximum wave height is in the waters of South Java, from West Java to East Java, reaching up to 3.5 meters. The highest maximum wave height in the waters of South Sukabumi to Garut in West Java is up to 3 meters. The lowest maximum wave height is in the waters of South Yogyakarta, between 0.5-1.5 meters.

During the West Wind season, the highest waves are in the waters of South Java, with an average maximum wave height from 00.00 to 18.00 UTC of around 3.5 meters. The dominant winds in the waters of South Java during the West Wind season blow from the Southwest to the Northwest, with an average wind speed between 5 and 15 knots [14]. During the West Wind season, air pressure in Asia is high and air pressure in Australia is low because the sun is located in the southern hemisphere. Therefore, the wind blows from Asia to Australia [11]. During the West Wind season in Indonesia, it tends to be rainy and the wind speed is low. The stronger the wind, the bigger the waves it produces, and vice versa when the wind is small, the waves it produces are also small [5].

3.2.2 Transition I Season

The map of the maximum wave height distribution during Transition I season (East to West monsoon transition) is shown in Figure 5.

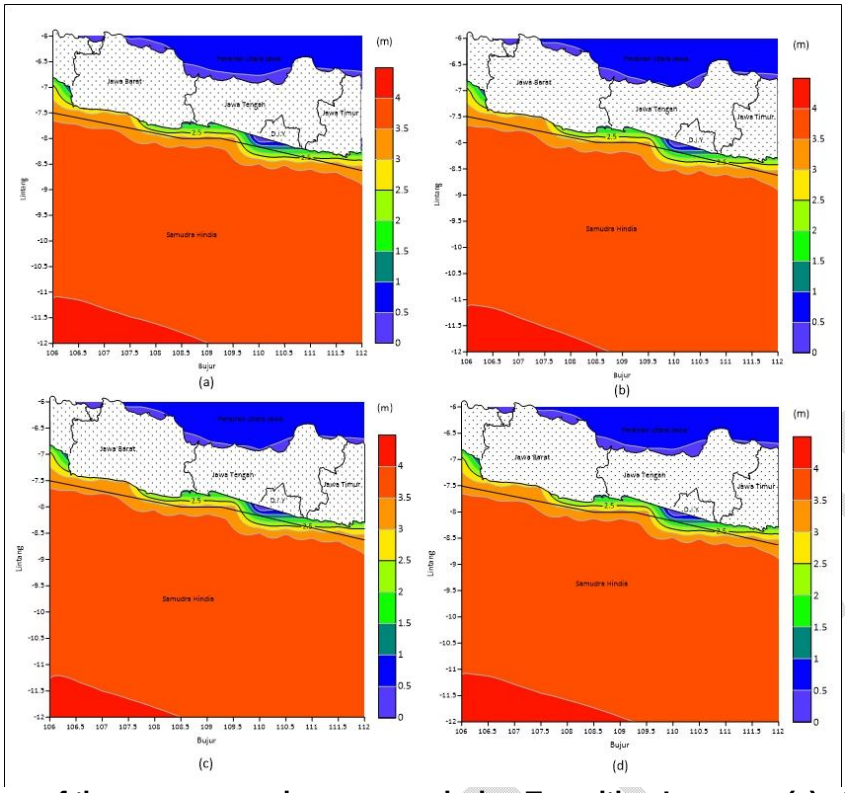

Figure 5. Distribution map of the average maximum wave during Transition I season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC.

Based on Figure 5, it is shown that during Transition Season I (transition of the Eastern Monsoon season) from 00:00 to 18:00 UTC, the highest maximum wave height in the waters of South Indian Ocean off West Java reaches up to 4 meters. For the waters off Sukabumi to Garut in West Java, the highest maximum wave height reaches up to 3 meters. The lowest maximum wave height in the waters off Pangandaran to Yogyakarta ranges from 0.5 to 2.5 meters.

During Transition Season I, there is a change in wind pattern in the waters off South Java, shifting from Westerly to Easterly winds. The westerly wind direction only occurs in March, while from April to May, the wind direction shifts to the east and southeast with speeds ranging from 5 to 10 knots [14]. Based on the distribution map of maximum wave height, an increase in wave height is observed during the transition from the Westerly Monsoon to Transition Season I, reaching up to 4 meters in the waters of South Indian Ocean off West Java.

3.2.3 East Wind Season

The distribution map of maximum wave height during the East Wind Season is shown in Figure 6.

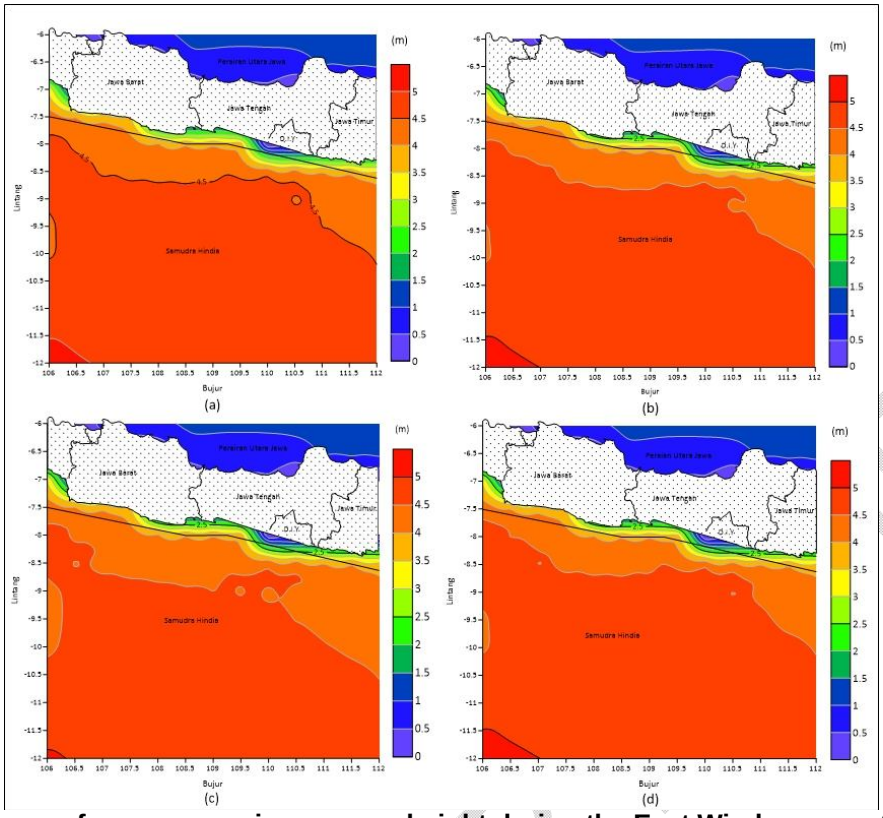

Figure 6. Distribution map of average maximum wave height during the East Wind season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC.

Based on Figure 6. during the East Monsoon season from 00.00 to 18.00 UTC, the maximum wave height in the waters of South Indian Ocean from West Java to East Java reaches up to 4.5 meters, and the highest in the South Java Sea region is around 5 meters on average. The highest wave height in the waters south of Sukabumi to Garut in West Java is around 4 meters. The lowest maximum wave height in the waters south of Pangandaran to Yogyakarta ranges from 0.5 to 2.5 meters.

During the East Monsoon season, the dominant wind direction in the waters of South Java blows from the East to Southeast, with an average wind speed of between 10 and 15 knotswhich indicates a higher average wind speed compared to the West Monsoon season, which ranges between 5 and 15 knots [14]. Similarly, the average maximum wave height is higher during the East Monsoon season, reaching up to 5 meters, while during the West Monsoon season, it reaches an average maximum wave height of 3.5 meters. This is in line with the statement by Kurniawan et al. (2011) that the greater the wind speed, the wider the frequency range and the greater the wave energy formed. During the East Monsoon season, the air pressure over the Asian continent is low, while the air pressure over the Australian continent is high because the sun is located in the northern hemisphere. Therefore, the wind moves from Australia towards Asia, causing the wind to move towards the southern open sea of Indonesia, resulting in high waves in the waters south of Java Island [11]. Additionally, the southern waters of Java Island directly face the Indian Ocean, causing high waves. This is consistent with previous research conducted by Kurniawan et al. (2012) that during the East Monsoon period, the areas susceptible to high waves in Indonesian waters are mostly located in the Indian Ocean from June to August.

3.2.4 Transition II Season

The distribution map of maximum wave height during the Second Transition Season is shown in Figure 7.

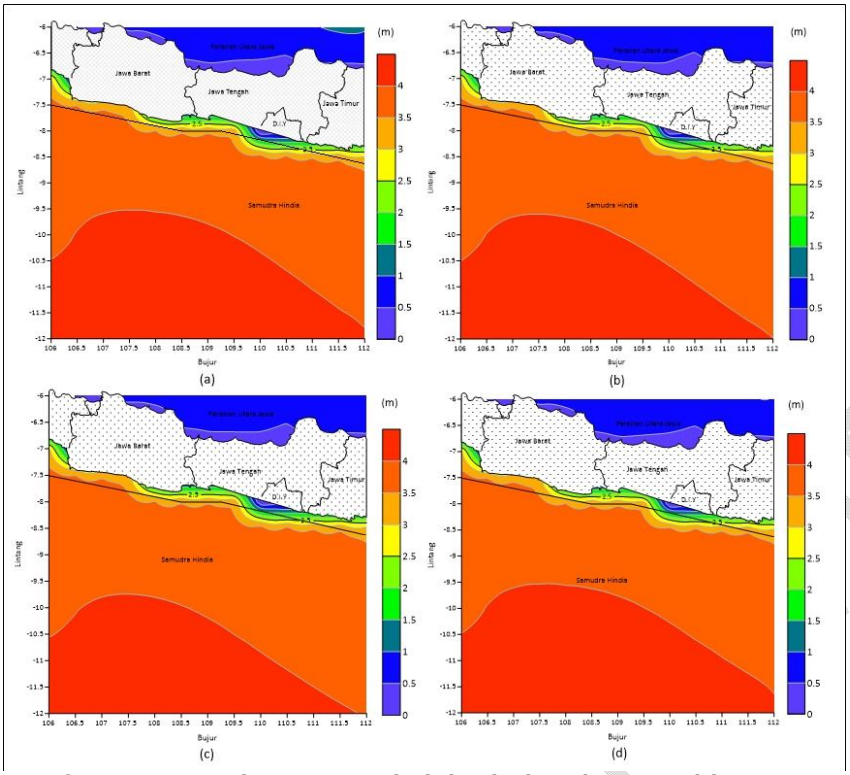

Figure 7. Distribution map of average maximum wave height during the Transition II season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC.

Based on Figure 7 shows that during the Second Transition Season from 00:00 to 18:00 UTC, the highest maximum wave height occurs in the waters of the southern Indian Ocean from West Java to East Java, reaching up to 4 meters. For the highest waters, it reaches up to 3.5 meters in the southern waters of Sukabumi to Garut, West Java. The lowest maximum wave height is found in the waters of southern Pangandaran to Yogyakarta, ranging from 0.5 to 2.5 meters. During the Second Transition Season, the dominant wind in the southern waters of Java blows from the Southeast with an average wind speed ranging from 5 to 10 knots [14]. Based on the distribution map of maximum wave height, a decrease in wave height occurs in the waters of the southern Indian Ocean from West Java to East Java, reaching up to 4 meters, when transitioning from the East Monsoon to the Second Transition Season. Meanwhile, during the East Monsoon, the wave height reaches up to 4.5 meters.

3.3 Maximum Average Wave Height of the Seasonal 11-Year Period

According to Kurniawan et al. (2011), there are two seasonal winds in Indonesia: the West Monsoon and the East Monsoon. The West Monsoon occurs from December to February, while the East Monsoon occurs from June to August. Between the West Monsoon and the East Monsoon, there is the First Transition Season, which occurs from March to May. From the East Monsoon to the West Monsoon, there is the Second Transition Season, which occurs from September to November.

The maximum average wave height in the waters south of Java Island varies each season. Based on the standard deviation calculation in Appendix 5, the maximum average wave height from high to low, based on the seasonal wind pattern in the waters south of Java Island, are as follows: East Monsoon (highest), Second Transition Season (high), First Transition Season (low), and West Monsoon (lowest). During the West Monsoon, the maximum wave height occurs at 12:00 UTC or 19:00 WIB, while during the First Transition Season, East Monsoon, and Second Transition Season, the maximum wave height occurs at 18:00 UTC. The maximum wave height tends to occur in the morning at 18:00 UTC or 01:00 WIB.

Among the four seasonal winds in Indonesia, the maximum average wave height in the waters of southern Java Island is highest in the southern Indian Ocean from West Java to East Java. For the highest waters, it reaches up to Sukabumi to Garut in West Java, and for the lowest waters, it is in Pangandaran to Yogyakarta. The variation in the distribution of maximum average wave height tends to occur in the waters due to the influence of coastal structures and the depth of the sea.

4. CONCLUSION

Based on the research results, it can be concluded that:

1. During the West Wind season (December, January, and February), the maximum wave height averages 3-3.5 meters in the South Indian Ocean region from West Java to East Java, while for the waters off the coast, the maximum wave height averages 2.5-3 meters in the southern waters of Sukabumi to Cianjur West Java, 1.5-2.5 meters in the southern waters of Garut to Pangandaran West Java to East Java, and 1-1.5 meters in the southern waters of Yogyakarta. During the East Wind season (June, July, and August), the maximum wave height averages 4-5 meters in the South Indian Ocean region from West Java to East Java, while for the waters off the coast, the maximum wave height averages 3.5-4 meters in the southern waters of Sukabumi to Cianjur, West Java, 2-3 meters in the waters off Garut to Pangandaran, West Java to East Java, and 1-2 meters in the southern waters of Yogyakarta.
2. The average maximum wave height tends to be high in the morning at 18.00 UTC or 01.00 WIB for the West Wind season, East Wind season, and Second Transition season. While during the West Wind season, the maximum wave height tends to be high at 12.00 UTC or 20.00 WIB.
3. The highest average maximum wave height occurs during the East Wind season.

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