



Study of Maximum Average Wave Height Distribution in the Southern Waters of Java Island during the Period 2010-2021

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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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 Indonesian Agency of Meteorology, Climatology, and Geophysics (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

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January 2010 to December 2021 at 00.00, 06.00, 12.00, and 18.00 UTC, with a latitude coordinate limit of 7°S to 12°S and longitude of 106°E to 112°E. 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 South Indian Ocean from West Java to East Java. The highest maximum wave height in the southern waters of Sukabumi-Garut West Java, and the lowest in the southernwaters of Pangandaran-Yogyakarta. The maximum average wave height tends to be high in the morning at 18.00 UTC for the Transition I, East Wind, and Transition II seasons. Meanwhile, during the WestWind season, the maximum wave height tends to be high at 12.00 UTC. The highest maximum average wave height occurred during the EastWind 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: West wind season; maximum wave height; surfer; southern waters of Java Island; east 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 km², including 3.25 million km² of the ocean and 2.55 million km² of the Exclusive Economic Zone [1]. Java Island is a densely populated island with a population of around 154.34 million people [2]. 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 [3]. 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 season.

The purpose of this study is to determine the distribution of average maximum wave height in the southern waters of Java Island and to identify the time and season when the average maximum 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 km². Astronomically, Java Island is located at 7°30'10" S, 111°15'47" °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 [4].

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 [5].

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 [6]. 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 [7].

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 [8].

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.

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 [9].

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 [10].

2. MATERIALS AND METHODS

This research is being conducted at the Indonesian Agency of Meteorology, Climatology, and Geophysics (BMKG) Tunggul Wulung Cilacap meteorological station during January-February 2023. The study area is located in the southern waters of Java Island, specifically in the geographic coordinates of 7 °S to 12 °S and longitude 106°E to 112 °E. The location map of the study is shown in Fig. 1.

2.1 Data Collection Method

2.1.1 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 0.25° x 0.25° in Network Common Data Form (NetCDF) format). The data used is the daily maximum wave height data that occurs and is recorded every day (for 24 hours) with a time division of every 6 hours for the period from January 2010 to December 2021 with a geographical boundary of 106°E in the west and 112°E in the east, as well as 7 °S in the north and 12°S in the south.

2.1.2 Wind season data in the South Waters Java Island

Wind season data, including the West Wind, the Transition I, the East Wind, and the Transition II, is used to determine the period of the average maximum wave height. The Transition season I is the transition season from the West to the East Wind season. The Transition season II is the transition season from the East Wind to the West Wind season, while the East Wind season occurs in June, July, and August, and the West Wind season occurs in December, January, and February [11].

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) every 6 hours.

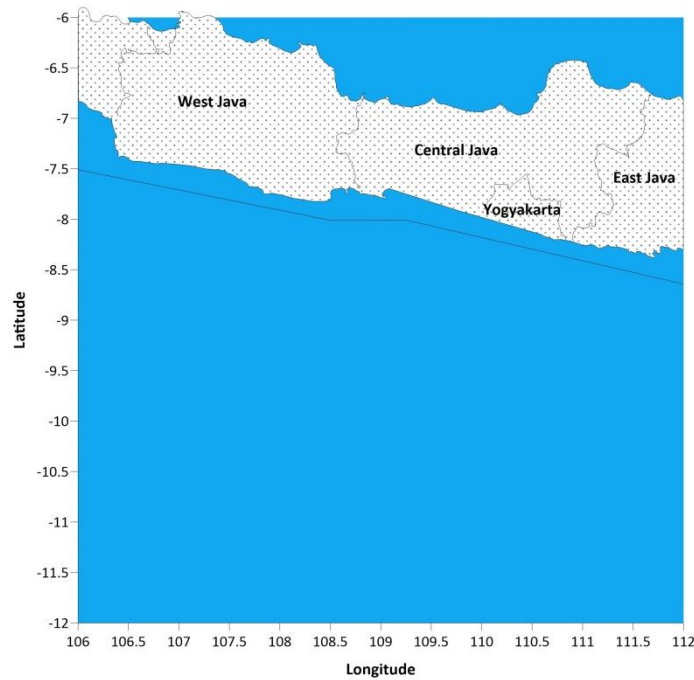


Fig. 1. Map of research locations

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 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 6 hours at 00.00, 06.00, 12.00, and 18.00 UTC in the southern waters of Java Island.

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.

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

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 every 6 hours in the southern waters of Java Island for the period from 2010 to 2021. The research flow diagram is shown in Fig. 3.



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

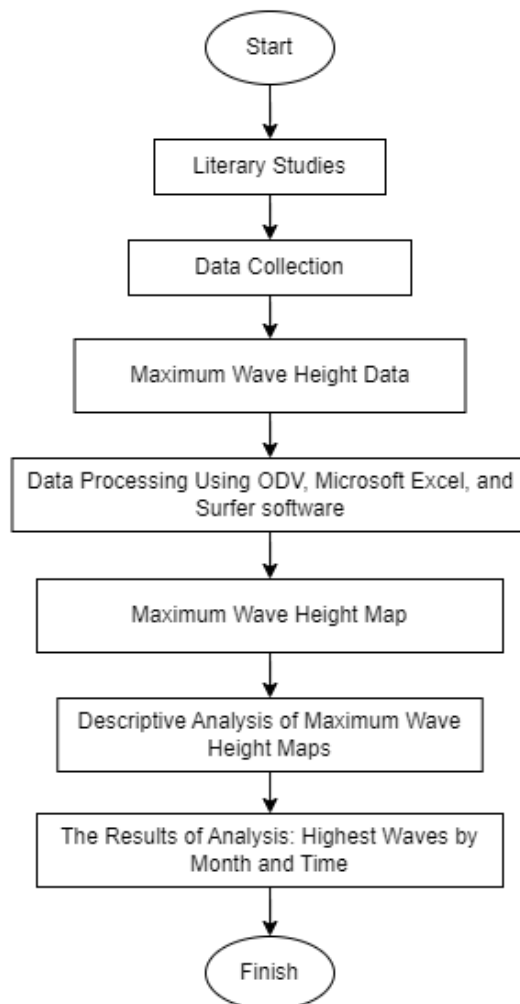


Fig. 3. Research flow diagram

3. RESULTS AND 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 6 hours at 00.00, 06.00, 12.00, and 18.00 UTC from January to December during the period from 2010 to 2021. Furthermore, the average maximum wave height was calculated for each season, namely the West Wind, Transition I, East Wind, and Transition II seasons. The results of the maximum wave height calculations for the West Wind season are shown in Table 2.

3.2 Maximum Wave Height Map

The Surfer software generated maps showing the distribution of maximum wave height for each season, including the West Wind, East Wind, Transition I, and Transition II seasons every 6 hours.

3.2.1 West wind season

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

Based on Fig. 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 Indian Ocean off West Java to East Java reaching up to 3.5 meters. The highest maximum wave height in the waters of Sukabumi to Garut

in West Java is up to 3 meters. The lowest maximum wave height is in the waters of 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 [12]. 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 [13]. 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 [14].

3.2.2 Transition season I

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

Based on Fig. 5, it is shown that during Transition Season I 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.

Table 2. Maximum average wave height during the West Wind season

| Average maximum wave height during the West Wind season(m) | | | | | |
|--|---------------|-----------|-----------|-----------|-----------|
| Longitude (°E) | Latitude (°S) | 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 |

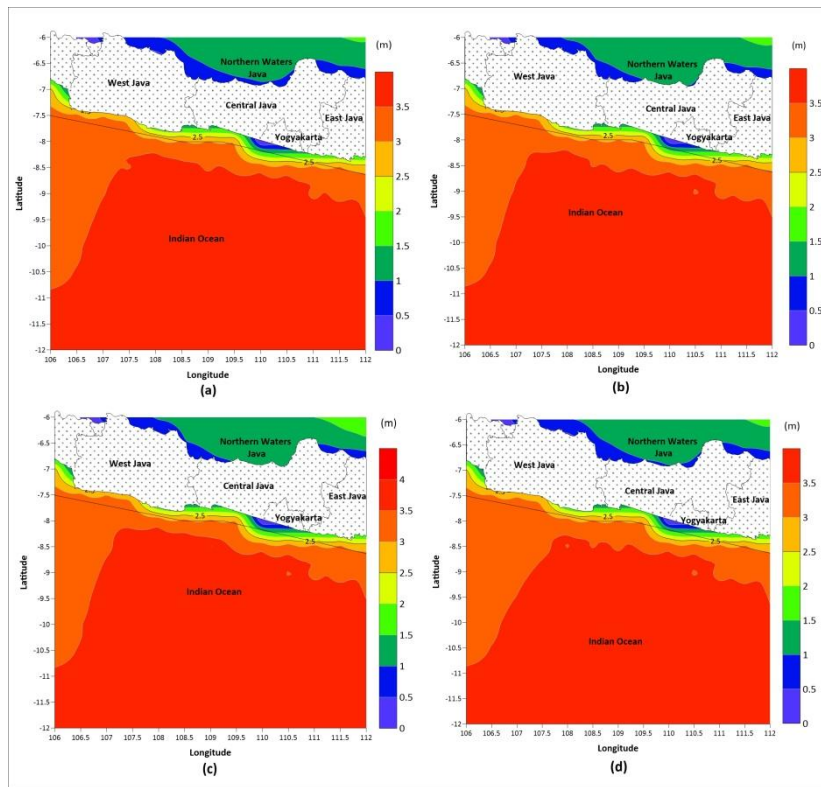


Fig. 4. Distribution map of the average maximum wave during the West Wind season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC

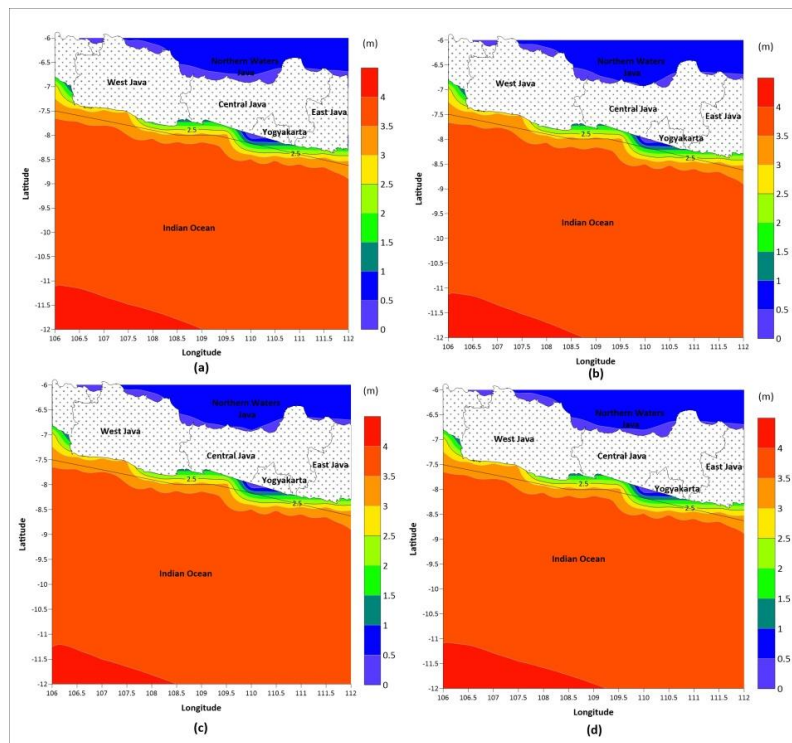


Fig. 5. Distribution map of the average maximum wave during Transition I season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC

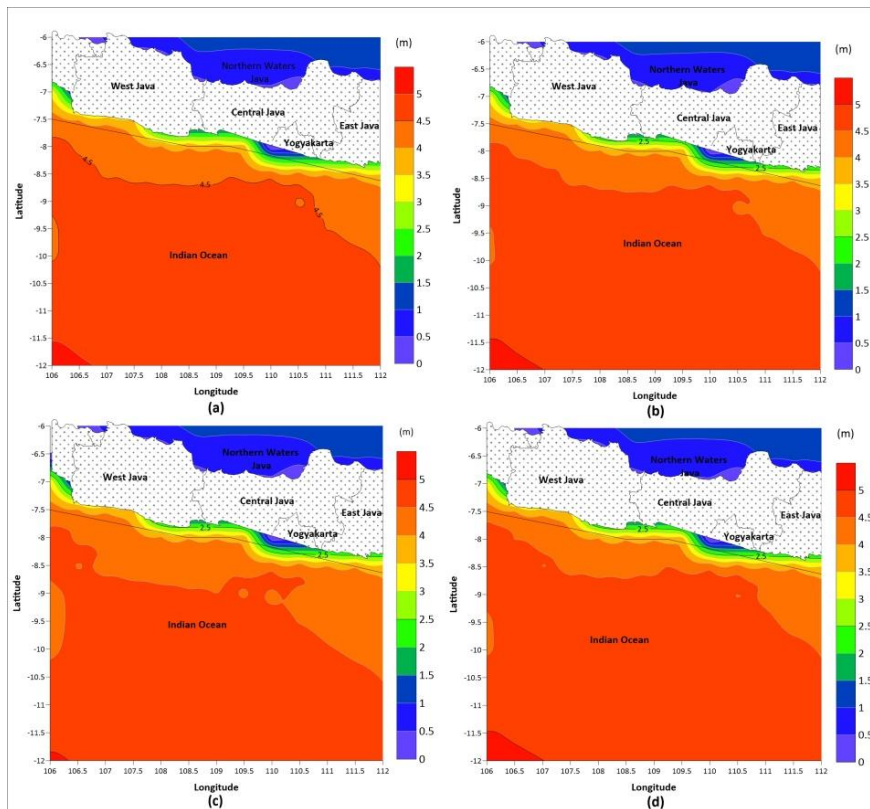


Fig. 6. Distribution map of average maximum wave height during the East Wind season: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC

During Transition Season I, there is a change in wind pattern in the southern waters Java, shifting from West to East wind season. The West Wind season 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 [12]. Based on the distribution map of maximum wave height, an increase in wave height is observed during the transition from the West Wind season 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 Fig. 6.

Based on Fig. 6. during the East Wind season from 00.00 to 18.00 UTC, the maximum wave height in the 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 southern waters of Sukabumi to Garut in West Java is around 4 meters. The lowest maximum wave height in the southern waters of

Pangandaran to Yogyakarta ranges from 0.5 to 2.5 meters.

During the East Wind 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 knots which indicates a higher average wind speed compared to the West Wind season, which ranges between 5 and 15 knots [12]. Similarly, the maximum average wave height is higher during the East Wind season, reaching up to 5 meters, while during the West Wind 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 Wind 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 southern waters of Java Island [13]. Additionally, the southern waters of Java Island directly face

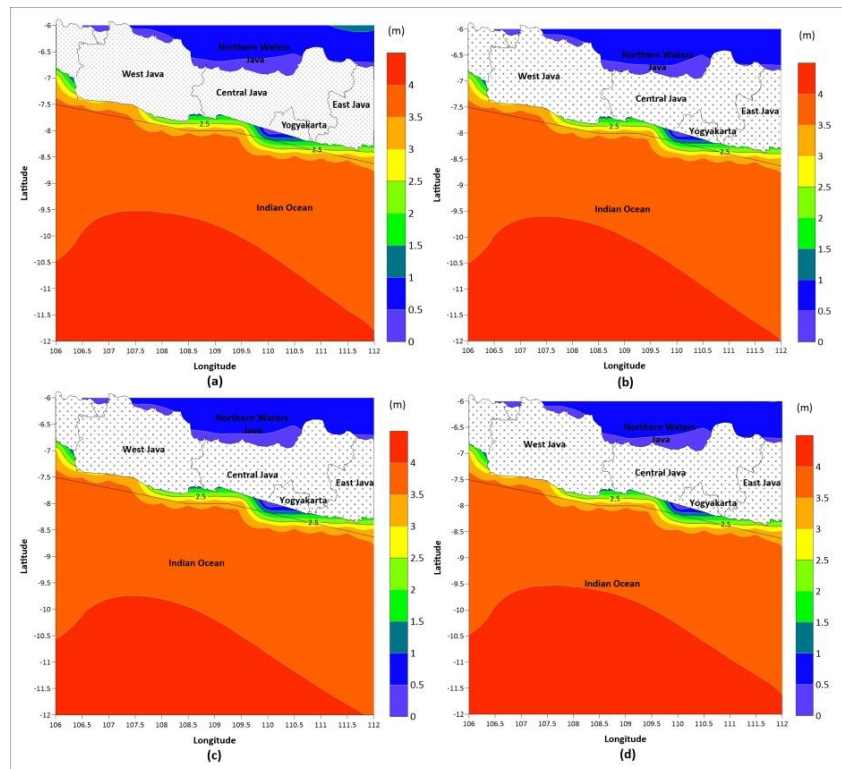


Fig. 7. Distribution map of average maximum wave height during the Transition season II: (a) at 00.00 UTC, (b) at 06.00 UTC, (c) at 12.00 UTC, and (d) at 18.00 UTC

the Indian Ocean, causing high waves. This is consistent with previous research conducted by Kurniawan et al. (2012) that during the East Wind season 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 season II

The distribution map of maximum wave height during the Transition season II is shown in Fig. 7.

Based on Fig. 7 shows that during the Transition season II from 00:00 to 18:00 UTC, the highest maximum wave height occurs in the waters of the South 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 waters of Sukabumi to Garut, West Java. The lowest maximum wave height is found in the waters of Pangandaran to Yogyakarta, ranging from 0.5 to 2.5 meters. During the Transition season II, the dominant wind in the southern waters of Java blows from the Southeast with an average wind speed ranging from 5 to 10 knots [12]. 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 Wind season to the Transition season II. Meanwhile, during the East Wind season, 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 Transition season I, which occurs from March to May. From the East to the West Wind season, there is the Transition season I, which occurs from September to November.

The maximum average wave height in the southern waters of Java Island varies each season. Based on the standard deviation calculation, the maximum average wave height from high to low based on the seasonal wind pattern in the southern waters of Java Island, are as follows: East Wind season (highest),

Transition season II (high), Transition season I (low), and West Wind season (lowest). During the West Wind season, the maximum wave height occurs at 12:00 UTC or 19:00 WIB, while during the Transition I, East Wind, and Transition II, 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 southern waters of Java Island is highest in the South 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 [15-22].

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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