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The Effect Of Tropical Cyclones On Extreme Weather And The Raising Of Wave Height In The Southern Region Of Indonesia To Espouse Sea Transportation Safety And Maritime Security (Case Study Of Tropical Cyclones Mangga, Lili, And Seroja)

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Abstract – Tropical cyclone cases can cause dangerous impacts on the maritime world, consequently, it is necessary to study the effects of extreme weather and also the raising wave height in the tropical cyclone area. This study aims to analyze the characteristics of tropical cyclones and their effect on extreme weather and sea wave conditions so that they can improve maritime safety and security better. The research method used in this study was descriptive quantitative by using data on 3 tropical cyclone cases from 2019 to 2021 within Indonesia's area of responsibility and using the "Ina-wave" model and "Himawari-8 satellite" data. The results of data processing presented that cyclone cases occurred in April and May and had maximum wind speeds ranging from 33 knots to 63 knots, those had been seen from the wave height that experienced a significant raising in the area around the occurrence of tropical cyclones, and experienced the raising in rainfall starting from 3 days before a tropical cyclone grew. It is hoped that this analysis of tropical cyclone cases can increase the awareness for parties of previous activities so that maritime safety and security can be safely maintained by knowing the characteristics of cyclones.

Keywords – maritime, satellite, tropical cyclone, wave

I. INTRODUCTION

Generally, a tropical cyclone is portrayed as a storm that has great power and has a low-pressure system over tropical or subtropical waters with a cluster of convective flows, moreover, this cyclone stands a surface wind circulation where the direction is counterclockwise in the northern hemisphere and clockwise in the southern hemisphere [1]. The average radius of a tropical cyclone is 150 to 200 km. Tropical cyclones form over enormous oceans which generally have warm sea surface temperatures of over 26.5 °C. Strong winds swirling near their center have wind speeds over 63 km/h. In addition, tropical cyclones can emerge due to the presence of warm and humid air masses and conditions in water areas so that they can drive atmospheric conditions to become unstable, these conditions can trigger convective between the atmosphere and the ocean, thus impacting convective cloud growth activity and affecting sea conditions, otherwise, sea conditions can also affect the dynamics of the atmosphere [2]. The construction of tropical cyclones typically emerges in the tropics which have low latitudes between 10º north latitude and 20º south latitude from the equator. Indonesia's territory which is located in the equatorial region drives this country to have a tropical climate. Hence, it can be considered that tropical cyclone is one of the common tropical disruptions. Nevertheless, the small est (close to zero) rotational effect or Coriolis style in the equatorial region forces tropical cyclones to rarely emerge in Indonesia [3].

This country is not a tropical cyclone growth area but is directly bordering on a tropical cyclone formation area. This makes Indonesia does not encounter a direct consequence, while the presence of tropical cyclones around Indonesia also decides weather patterns throughout Indonesia [4]. In recent years Tropical Cyclones have expanded in this country's territory, indicating that climate change can raise the growth of Tropical Cyclones which are initiating to get closer to the equator where in fact until 2022 there have been at least 10 cyclones growing in Indonesia's Area of responsibility. Those are originally named and including Tropical Cyclone *Durga* in 2008, Tropical cyclone *Anggrek* in 2010, tropical cyclone *Bakung* in 2014, Tropical Cyclone *Cempaka* in 2017, Tropical Cyclone *Dahlia* in 2017, Tropical Cyclone *Flamboyan* in 2018, Tropical Cyclone *Kenanga* in 2018, Tropical Cyclone *Lili* in 2020, Tropical Cyclone *Mangga* in 2021 and Tropical Cyclone *Seroja* in 2022. According to this historical data, it can be noticed that there has been a raising point in the incidence of tropical cyclones where one of the factors raising the growth of tropical cyclones is the effect of climate change. So that in the context of opposing climate change, reducing greenhouse gas emissions has evolved as a real concern for the maritime community [5]. Consequently, by suppressing climate change, the potential for tropical cyclones will not raise from year to year.

The effect of tropical cyclones is influenced by the position and intensity of the cyclone and relies on air circulation factors in the surrounding area [6]. In general, the occurrence of tropical cyclones can also trigger high waves and extreme weather around the formation area and its surroundings. The country that is affected in this case, is Indonesia. In widespread, Indonesia is included in the maritime country, where this country is geographically located in two oceans, namely the Pacific and Indian oceans, and is a link between the Asian continent and the Australian continent. Astronomically the location of Indonesia's territory is at latitude 60 north latitudes and 110 south latitudes and is located at 950 east longitudes to 1410 east longitude. Based on this, it can be inferred that Indonesia is significantly close to the formation of tropical cyclones and can be an area for tropical cyclones to form so that weather disturbances and raised wave height can emerge in Indonesian territory. These weather disturbances can disrupt shipping activities and maritime safety. Maritime safety is one of the factors for maintaining national security, in this case, security is a form of protection to secure both at the individual, ethnic, environmental, and state levels for the survival of its citizens [7]. Security itself is divided into several sectors including military, political, environmental, economic, and social [8]. The concept of security must be outlined in the form of maritime security by countries that have an enormous maritime area. This security is an issue that is widely discussed and attracts the attention of the entire world community. In the modern era, the safety of navigation, prosecution of transnational crimes including sea piracy and maritime terrorism, as well as conflict prevention and resolution are concerns in maritime security. In the context of non-traditional security, the issues of maritime environmental security, search, and safety appear in the maritime environment [9]. This security can be constructed in a matrix by connecting concepts such as "Marine Safety, Seapower, Blue Economy and Resilience" [10]. As a result, the occurrence of tropical cyclones, both directly and indirectly, can disrupt shipping activities and maritime security.

Based on the issues above, a tropical cyclone case can, directly and indirectly, disrupt fishing activities and maritime security. Therefore, discussing extreme weather and increasing wave height due to tropical cyclone events is very necessary for further research. So that parties of the maritime world can survive and comprehend tropical cyclone cases to maintain their safety and security from the effects caused by tropical cyclones that will happen in the future.

II. Methodology

The research method used in this research was a quantitative descriptive method. This method intends to describe the data by analyzing the data obtained to get a clear picture [11]. The quantitative descriptive method is a method that emphasizes the objective measurement aspects of social phenomena, while data from quantitative research is processed and can be analyzed using statistical calculations.

The data employed in this study were tropical cyclone data (*Mangga*, *Lili*, and *Seroja*), wave height data, and weather satellite data. For tropical cyclone data retrieved from the web https://sharaku.eorc.jaxa.jp/cgi-bin/typ_db/typ_db.cgi. The wave height data employed the Ina-Waves wave modeling data belonging to the Meteorology, Climatology, and Geophysics Agency, which was the third generation of spectral waves (Wavewatch III). Then the data was paired with a shallow or nearshore wave model (Simulated Waves Nearshore - SWAN) using the nesting method. Ina-Waves has used the latest Bathymetry as an input model in the expectancy of meeting the demands for better accuracy and quality of ocean wave information to support the safety and efficiency of various marine activities. The Ina-Wave data obtained was multidimensional in NetCDF format. Multidimensional data was data that has more than 2 dimensions. Weather parameter data such as air temperature data that were arranged spatially based on latitude and longitude at a certain time range can be named multidimensional data. For example, having data for a certain area in the form of a grid and organized like sheets on a stack of paper arranged in a landscape manner, the length, width, and thickness of the stack of paper are called dimensions. On this pile of paper, the length of the paper is called the longitude dimension, the width of the paper is called the latitude dimension, and the thickness of the paper is called the time dimension [12] [13]. For weather satellite data using the Himawari-8 satellite. Satellites were required not only for communication purposes but also to obtain spatial data that supports intelligence [14]. In this case, intelligence was something that described the condition of a tropical cyclone which in the future can identify the characteristics of a tropical cyclone and was used for shipping safety and maritime security. In addition, the Himawari-8 weather satellite can reach all parts of Indonesia in real-time every ten minutes. Therefore, this satellite can be used to monitor the weather in a large area of Indonesia, and weather formation is very complex [15]. The Himawai-8 satellite data used in this study was product data in the form of GSMaP data. GSMaP stood as a derivative product of weather satellite data which aimsed to estimate rainfall intensity. With this rainfall intimacy, the areas where extreme rain occurred, especially when tropical cyclone occurs can be discovered.

III. FINDINGS AND DISCUSSION

In the case of shipping safety, the case of tropical cyclones had been indicated as one of the most dangerous factors. Therefore, to anticipate accidents and disturbances in the area of shipping, knowing the characteristics of tropical cyclones was necessary. By understanding this, the characteristics of the occurrence of tropical cyclones *Mangga*, *Lili*, and *Seroja* were discussed in this study. More details had been found and presented as follows:

3.1. Tropical Cyclone Lili

Tropical cyclone *Lili* was constructed from 9 to 11 May 2019. This cyclone was formed in the Banda Sea south of Ambon. Meanwhile, the area affected by this cyclone was the Southwest Maluku Islands Region, Timor Island, and NTT Waters. To catch the movement of this cyclone can be seen in the following figure:

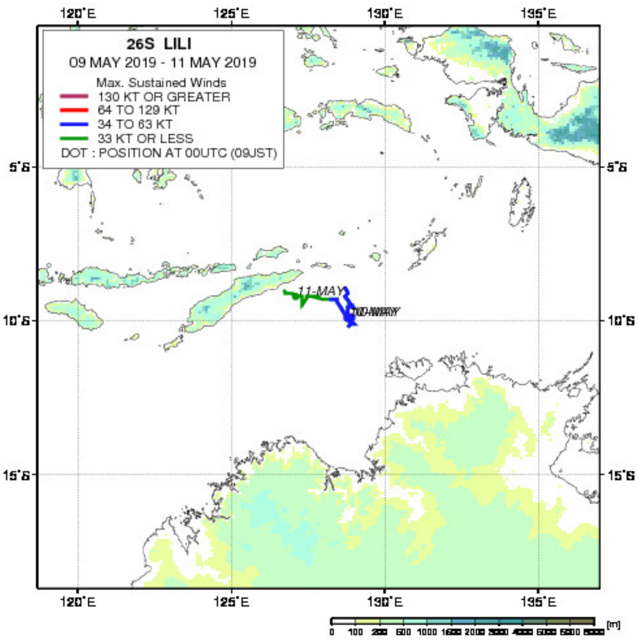
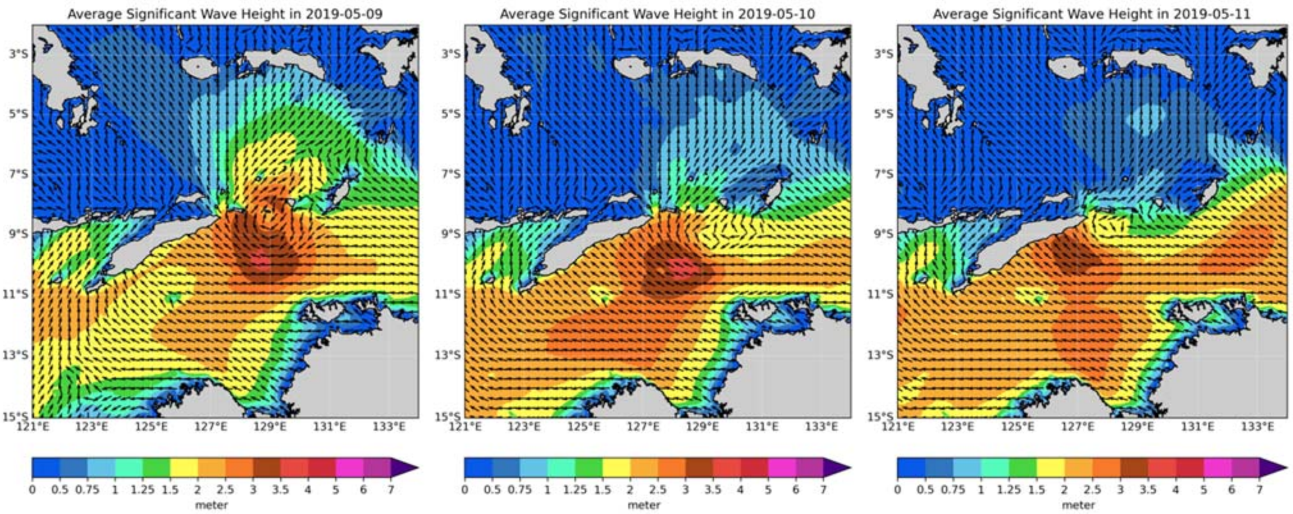
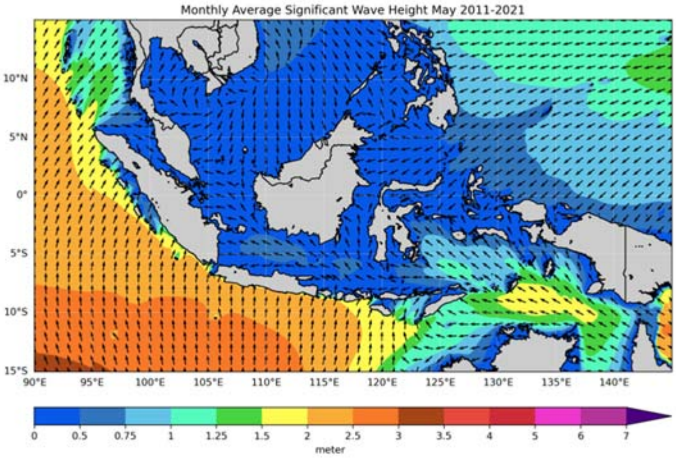


Figure 1. The Tropical Cyclone Trajectory of *Lili*

Based on figure 1. It can be noticed that tropical cyclone *Lili* has a maximum wind speed of 33 knots to 63 knots. Its Wind speed had many harmful effects on sea transportation and maritime parties. Tropical Cyclone *Lili* caused the raising wave height in the Tropical Cyclone Region and the surrounding areas. To find out the wave height when a tropical cyclone occurs, it can be seen the following figures:



(a) (b) (c)



(d)

Figure 2. (a) Wave Height during a Tropical Cyclone on 9 May 2019; (b) Wave Height during a Tropical Cyclone on 10 May 2019; (c) Wave Height during a Tropical Cyclone on 11 May 2019; (d) Climatology of waves in May

Based on figure 2. It can be seen that the wave height on May 9, 2019, ranged from 2.5 to 5 meters. For May 10, 2019, the wave height reaches 2 to 5 meters. Whereas on May 11, 2019, the wave height ranged from 2 to 3.5 meters. Climatologically, in May the wave height in the area ranges from 0.75 to 2 meters. Consequently, it can be concluded that when tropical cyclone *Lili* occurs, the wave height raised significantly, which was usually 0.75 to 2 meters to 2.5 to 5 meters. By understanding this expansion, it was very necessary to be vigilant and careful when cyclones occurred for the parties who worked in maritime activities, both shipping and other maritime activities.

When sea waves underwent a significant increase, fishermen must also be conscious of extreme weather that occurred in tropical cyclone areas. These weather extremes, in general, included heavy rains, cold winters, floods, and typhoons [16]. However, the focus case in this study was the rain that stood at more than 100 mm/day, which was a concern when a tropical cyclone occurred. To better understand Extreme Weather in the condition of extreme rain when Tropical Cyclone *Lili* emerged, it can be caught in the following figures:

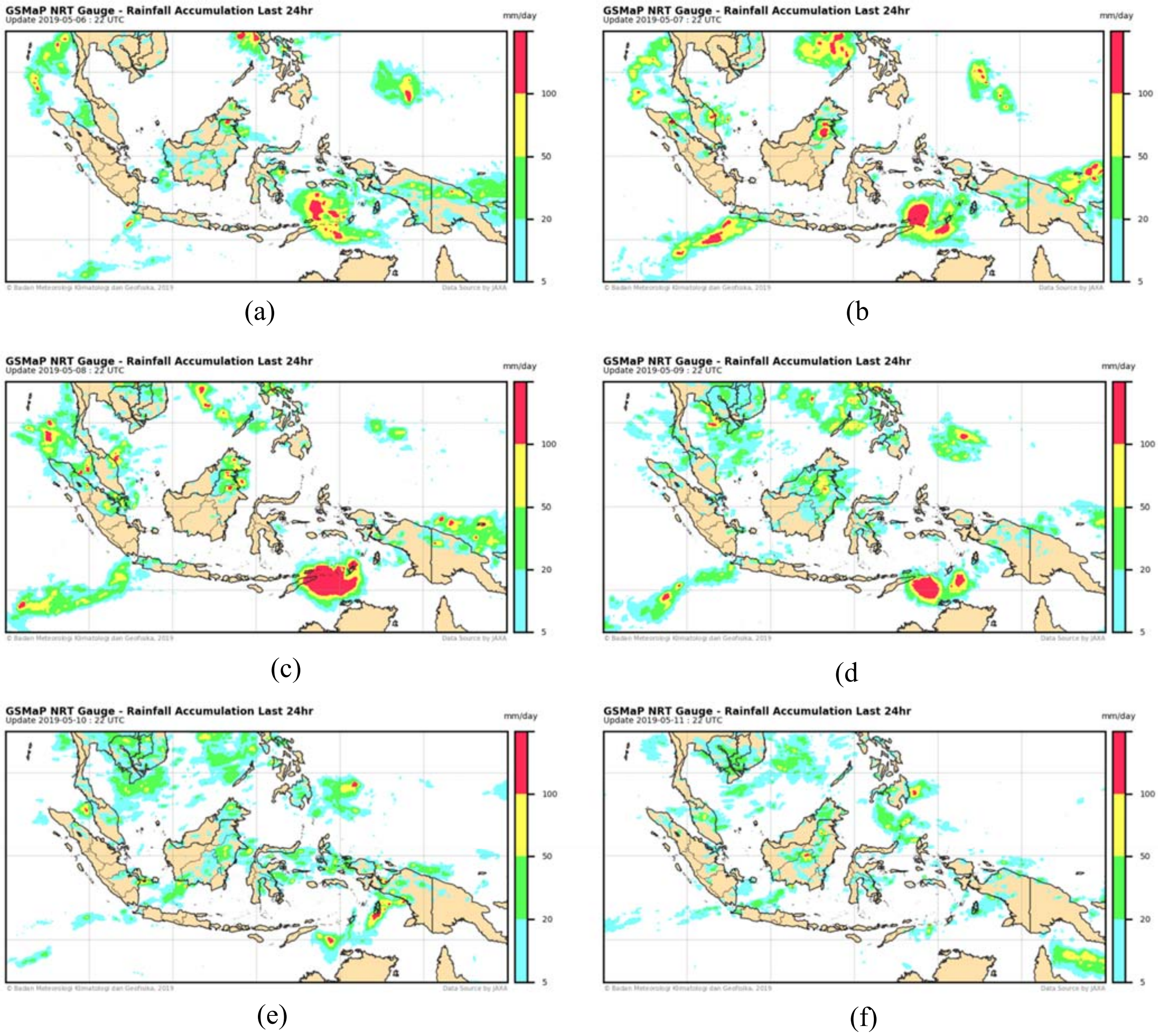


Figure 3. (a) The accumulation of rainfall on 6 May 2019; (b) The accumulation of raintall on 7 May 2019; (c) The accumulation of rainfall on 8 May 2019; (d) The accumulation of rainfall on 9 May 2019; (e) The accumulation of rainfall 10 May 2019; (f) The accumulation of rainfall on 11 May 2019

Based on figure 3. It was comprehended that extreme weather could occur 3 days before the growth of tropical cyclone *Lili*. This extreme weather was rain above 100 mm/day that emerged around the tropical cyclone *Lili*, namely in the Southwest Maluku Islands, Timor Island, and East Nusa Tenggara waters. The increase in rainfall in the region emerged from May 6 to May 10, 2019. Extreme rain began to reduce when the tropical cyclone *Lili*es began to end. Based on this description, it was known that tropical cyclone *Lili* could cause extreme weather even 3 days after the cyclone was formed.

3.2. Tropical Cyclone Mangga

Tropical cyclone *Mangga* began on 20 to 25 April 2020 and was located in the southwest of Bengkulu, to be precise, at coordinates 9.80 south latitude and 93.00 east longitudes in the Indian Ocean. This cyclone did not pass through Indonesian territory though could still affect oceanographic parameters in Indonesia, especially in the South Java Waters. Consequently, the occurrence of this tropical cyclone can disrupt shipping and maritime activities. To see the trajectory of the *Mangga* Cyclone can be seen in the figure below:

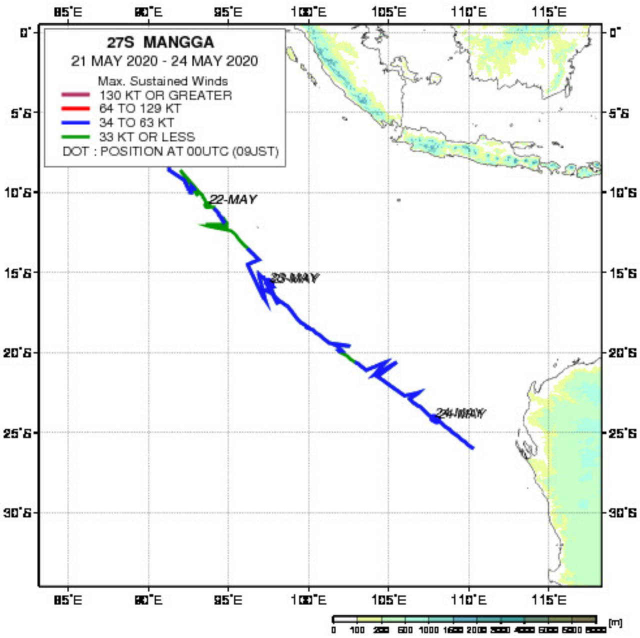
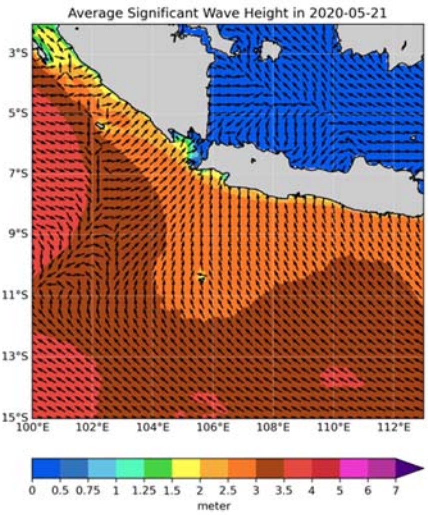
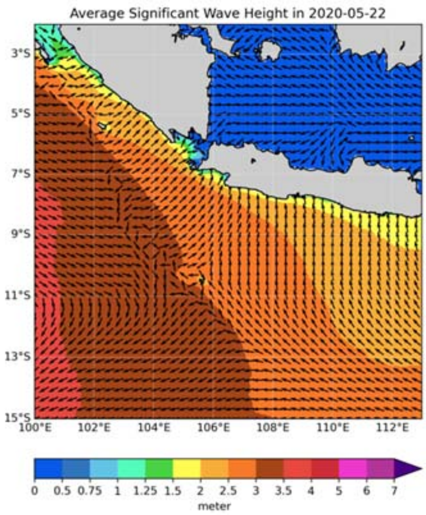


Figure 4. The Tropical Cyclone Trajectory of *Mangga*

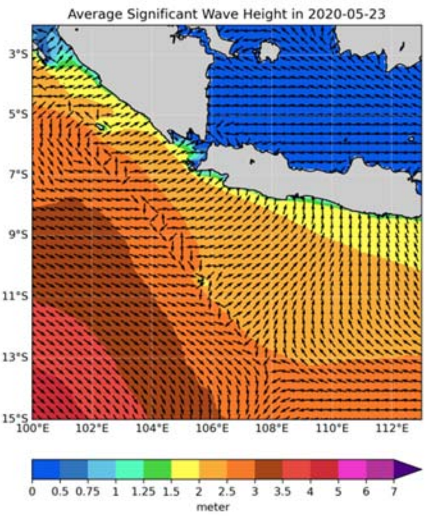
Based on this figure, it can be illustrated that the trajectory of tropical cyclone *Mangga* was heading southeast with a route away from Indonesia and approaching Australia. The maximum wind speed for this tropical cyclone ranged from 33 knots to 63 knots. To see the wave height when the tropical cyclone emerged, check the figure below:



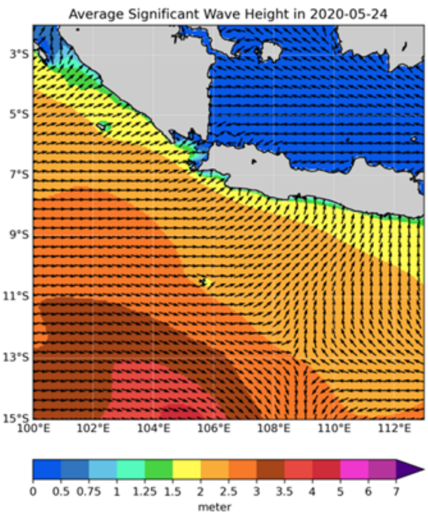
(a)



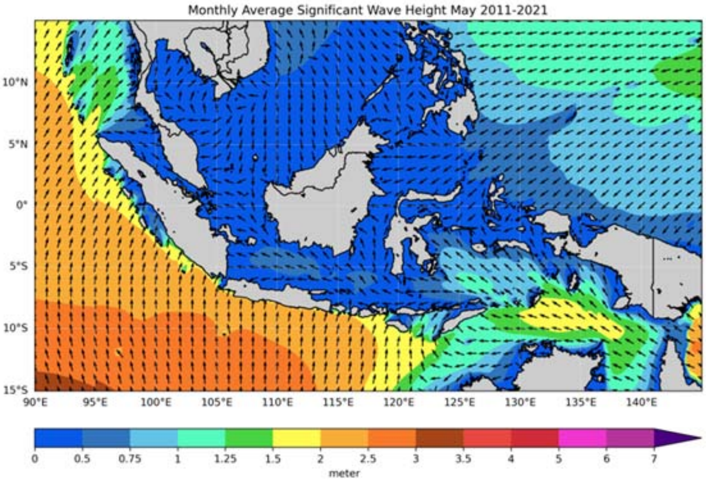
(b)



(c)



(d)



(e)

Figure 5. (a) wave height on May 21, 2020; (b) wave height on May 22, 2020; (c) wave height on April 23, 2020; (d) wave height on April 24, 2020; (e) Wave climatology in May.

Based on Figure 5. It seemed that the wave height in the waters of West Sumatra, Bengkulu, Lampung, Banten, and West Java on April 21, presented the wave height between 2.5 to 5.0 meters. Whereas on April 22 showed a wave height between 2.5 to 4 meters, then on April 23 was seen between 2.0 to 3.5 meters, and last on April 24, the wave height was between 2.0 to 3.5 meters. On the other hand, climatologically waves during April in the region ranged from 2.0 to 3.0 meters. Based on the data above, it can be concluded that tropical cyclones can raise wave height from an average wave of 2.0 to 3.0 meters and change to 2.5 to 5.0 meters. The increase was quite significant so it greatly disrupted shipping and maritime activities.

In addition to raising wave height, one of the effects caused by tropical cyclones was the emergence of extreme weather around its region and the formation area of the tropical cyclone. To see the potential for extreme weather can be seen in the following weather satellite proof:

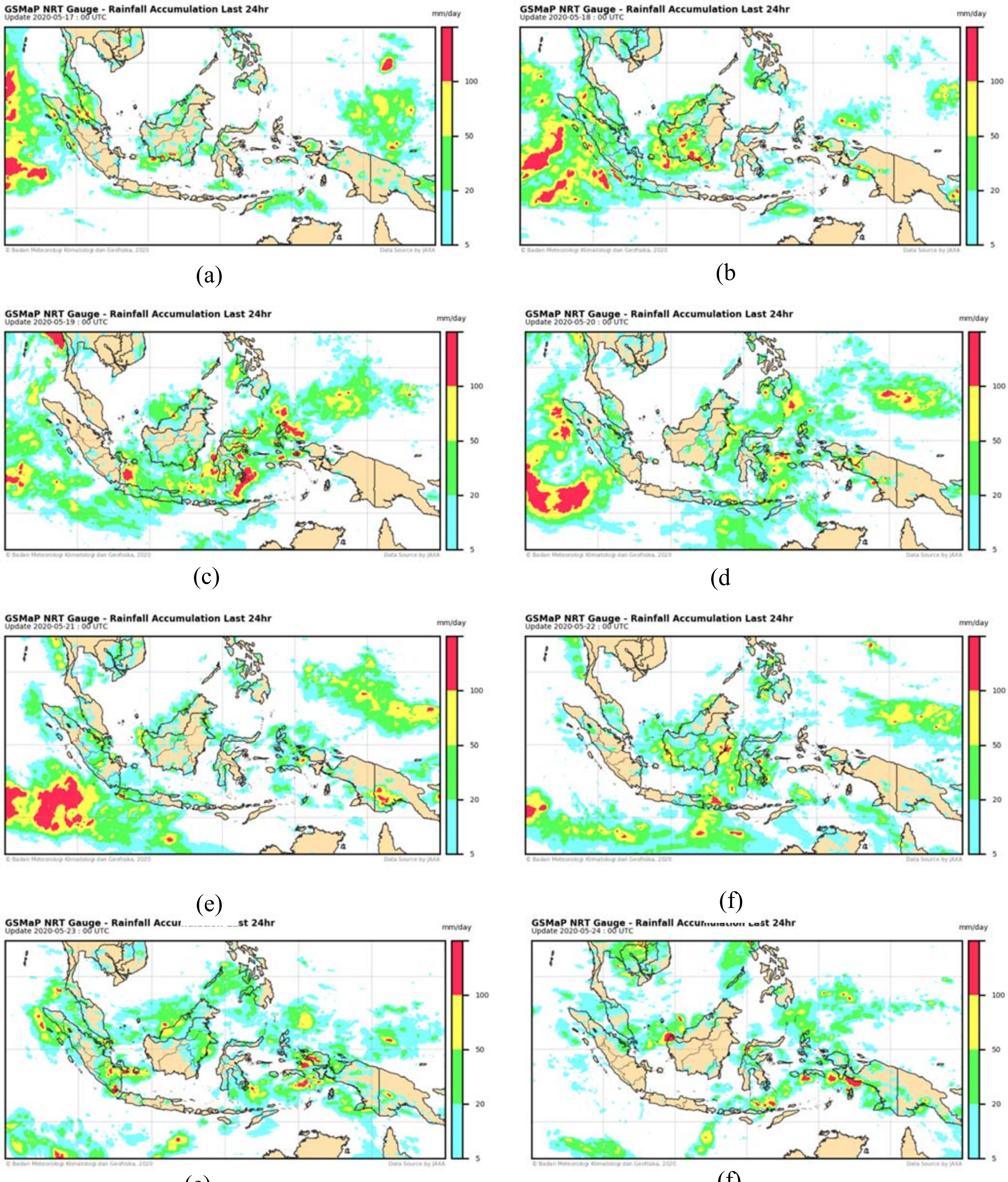


Figure 6. (a) The accumulation of rainfall on May 16, 2020; (b) The accumulation of rainfall on May 17, 2020; (c) The accumulation of rainfall on May 18, 2020; (d) The accumulation of rainfall on May 19, 2020; (e) The accumulation of rainfall on May 20, 2020; (f) Rainfall accumulation on May 21, 2020.

Based on Figure 6. The tropical cyclone affected the emergence of extreme weather in the area which was passed and the area around the incidence of tropical cyclones. That could be noticed from the figure that before the tropical cyclone happened on May 16, 2020, where rainfall around the region indicated a weight above 100 mm/day. The rain stayed until the growing and developing cyclone. This happening stayed until May 22, 2020. Whereas on May 23, 2020, the condition had begun to decrease because the direction of the cyclone had already known the area of the formation and also the tropical cyclone had begun to become extinct so the potential for extreme rain began to decrease as well.

3.3. Tropical Cyclone Seroja

Tropical cyclone *Seroja* was a tropical cyclone whose cyclone began on April 4, 2021, to 12 April 2021 in the Nusa Tenggara region. This cyclone moved from the territory of Indonesia and then crossed the west coast of Australia. East Nusa Tenggara regions, West Nusa Tenggara waters, Bali, East Java, and Central Java were areas affected by this cyclone. To see the tropical cyclone track of *Seroja* can be seen in the figure below:

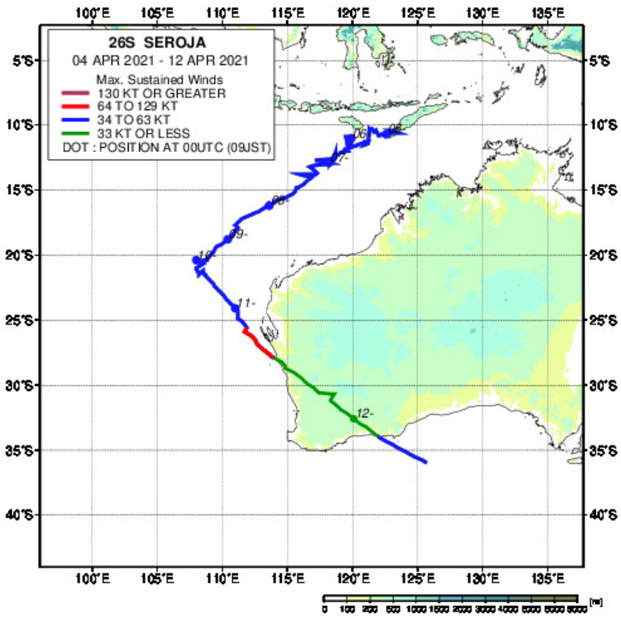
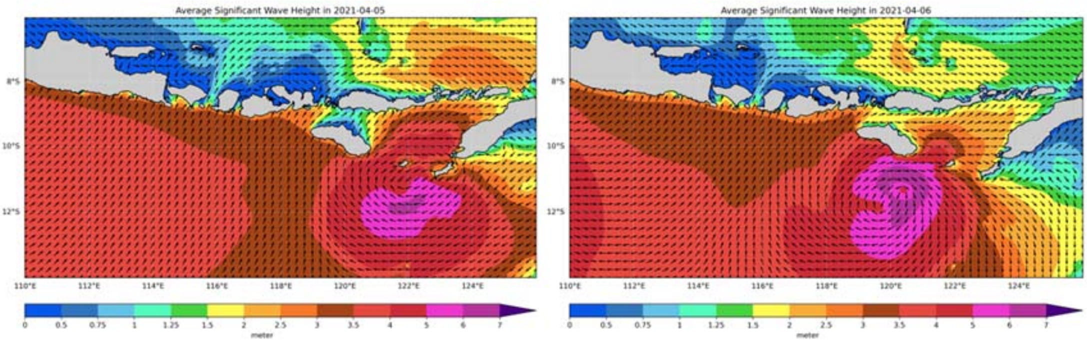
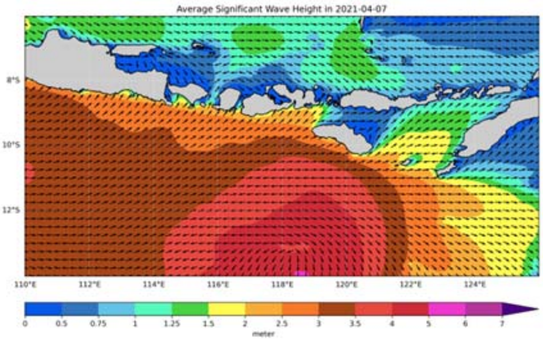


Figure 7. Trajectory Cyclone *Seroja*

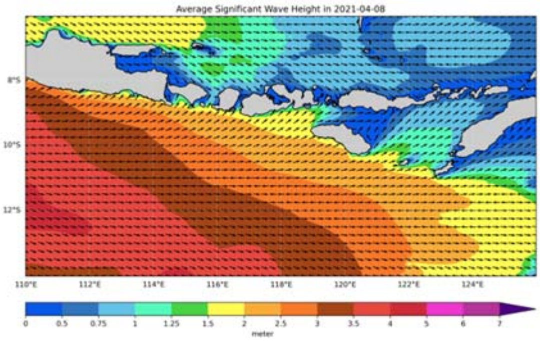
Based on Figure 7, it can be seen that the cyclone trajectory was quite extended where the occasion lasted up to 8 days. The route was taken from East Nusa Tenggara to Australia. The maximum wind speed for this tropical cyclone varies, when the cyclone was in Indonesian territory, the maximum wind speed reached 34 knots to 63 knots. Meanwhile, this tropical cyclone had maximum wind speeds ranging from 33 knots to 129 knots in Australia. The increase in wave height when the *Seroja* Tropical Cyclone happened could be seen in the following figures:



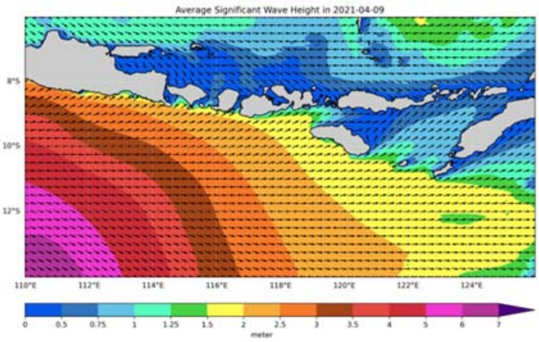
(a) (b)


Average Significant Wave Height in 2021-04-07
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

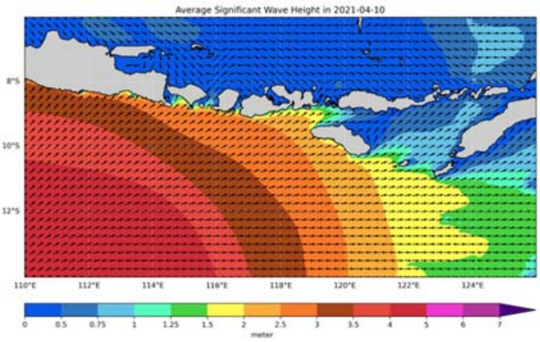
(c)


Average Significant Wave Height in 2021-04-08
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

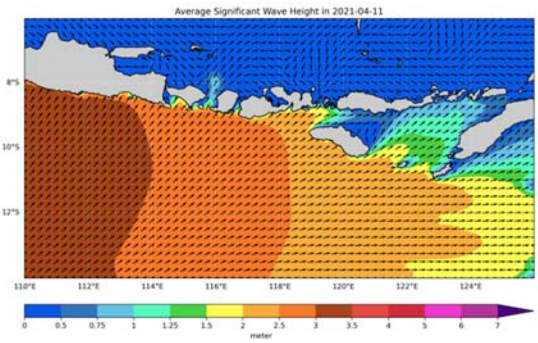
(d)


Average Significant Wave Height in 2021-04-09
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

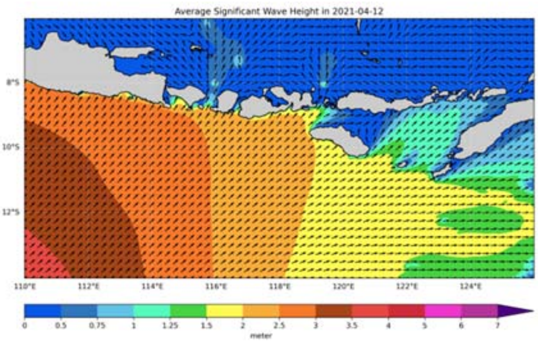
(e)


Average Significant Wave Height in 2021-04-10
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

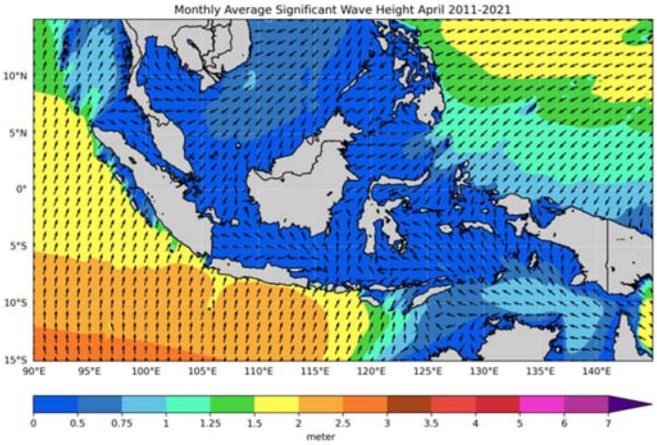
(f)


Average Significant Wave Height in 2021-04-11
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

(g)


Average Significant Wave Height in 2021-04-12
8°S
10°S
12°S
110°E 112°E 114°E 116°E 118°E 120°E 122°E 124°E
0 0.5 0.75 1 1.25 1.5 2 2.5 3 3.5 4 5 6 7
meter

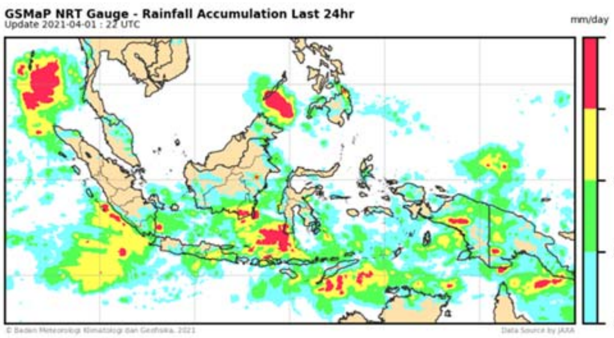
(h)



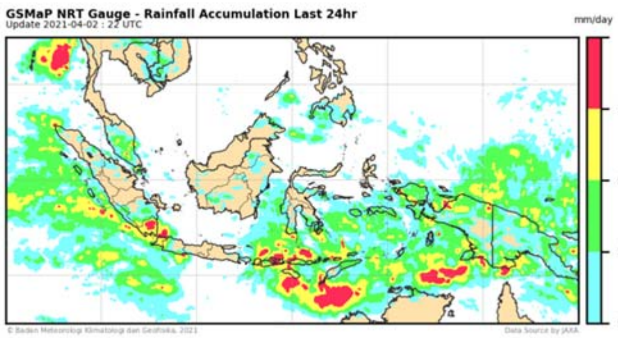
(i)

Figure 8. (a) Wave height on 5 April 2021; (b) Wave height on 6 April 2021; (c) Wave height on 7 April 2021; (d) Wave height on 8 April 2021; (e) Wave height on 9 April 2021; (f) Wave height on 10 April 2021; (g) Wave height on 11 April 2021; (h) Wave height on 12 April 2021; (i) Wave Climatology in April.

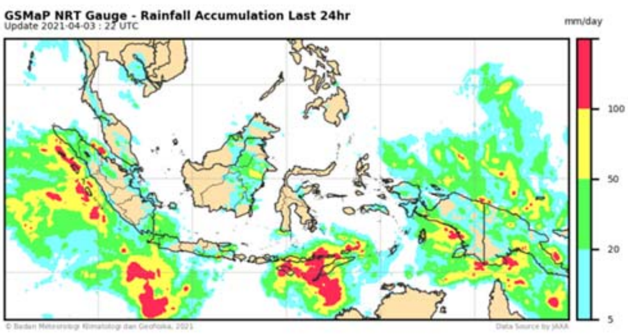
Based on Figure 8. When a tropical cyclone occurred, the wave height from 5 to 12 April in the East Nusa Tenggara, West Nusa Tenggara waters, Bali, East Java, and Central Java ranged from 2.0 to 7 meters. These waves could be categorized as high waves, so they could endanger shipping and other maritime activities. When compared with the April wave climatology data, the height of the waters in the area ranged from 0.75 to 2.5 meters. Based on this it was clear that the tropical cyclone of *Seroja* could increase the wave height significantly which generally ranged from 0.75 to 2.5 meters, and had increased significantly from 2 to 7 meters. This significant increase should be a warning for maritime parties to be vigilant when a tropical cyclone occurred. The effects of extreme weather in the form of rain above 100 mm/day can be seen in the following Himawari-8 satellite products:



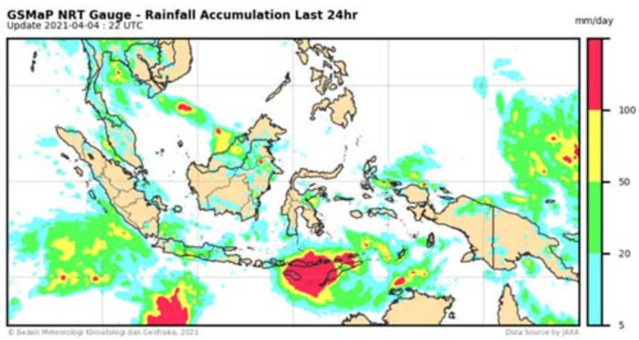
(a)



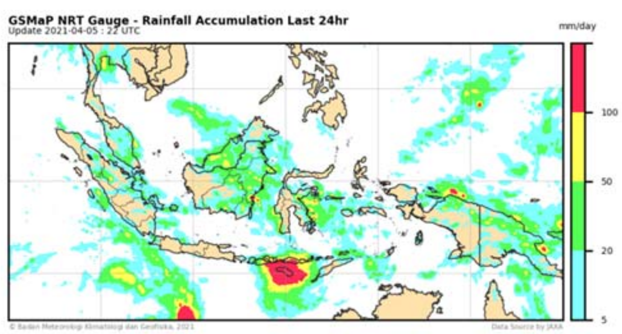
(b



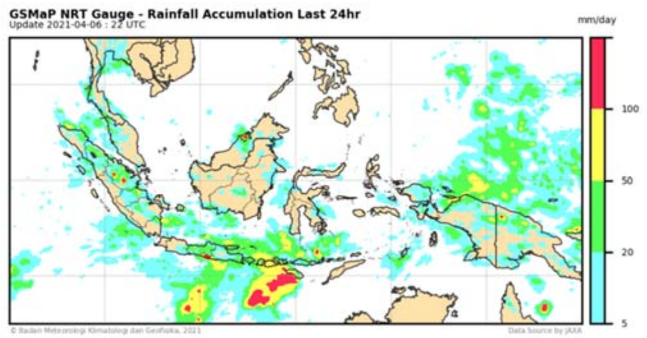
(c)



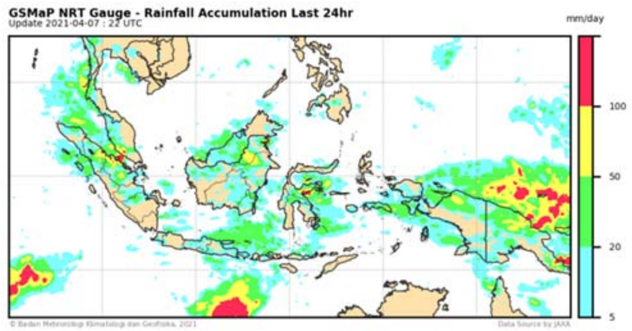
(d)



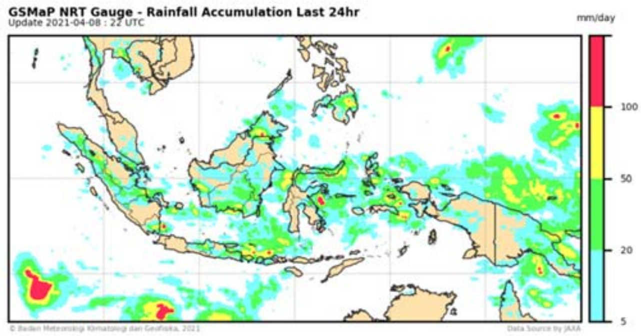
(e)



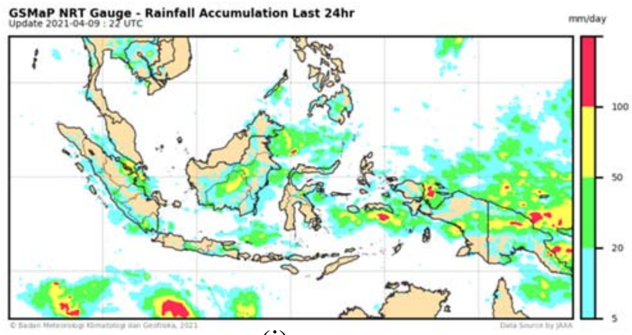
(f)



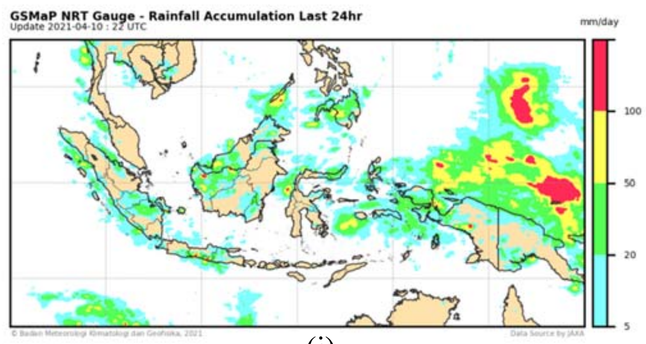
(g)



(h)



(i)



(j)

Figure 9. (a) The accumulation of rainfall on 1 April 2021; (b) The accumulation of rainfall on 2 April 2021; (c) The accumulation of rainfall on 3 April 2021; (d) The accumulation of rainfall on 4 April 2021; (e) The accumulation of rainfall on 5 April 2021; (f) The accumulation of rainfall on 6 April 2021; (g) The accumulation of rainfall on 7 April 2021; (h) The accumulation of rainfall on 8 April 2021; (i) The accumulation of rainfall on April 9, 2021; (j) The accumulation of rainfall on 10 April 2021.

Based on figure 9. It was known that rainfall contained 100 mm/day beginning from 1 April 2021 or 3 days before the tropical cyclone *Seroja* grew. The rain stayed until April 7 2021 and slowly decreased as the tropical cyclone moved away from Indonesia towards Australia. Based on these data, it could be noticed that the extreme rain initiated 3 days before the tropical cyclone grew. The tropical cyclone of *Seroja* stood as one of the tropical cyclones that claimed many lives, especially in the area where the tropical cyclone grew, which was in the East Nusa Tenggara region. Data from the National Disaster Management Agency recorded that the Tropical Cyclone of *Seroja* caused 152 deaths, 51,879 houses were damaged and 3,920 public facilities were wrecked.

IV. Conclusion

Based on the research findings and discussion above, it can be concluded that the occurrence of Tropical Cyclones *Lili*, *Mangga*, and *Seroja* emerged in April and May. In addition, cyclones have a maximum wind speed of between 33 knots and 63 knots.

While the increase in wave height for Tropical Cyclone *Lili* from normal conditions is usually 0.75 to 2 meters becomes 2.5 to 5 meters. Second, in Tropical Cyclone Mango, the normal wave height of 2.0 to 3.0 meters changes to 2.5 to 5.0 meters. Third, the increase in wave height during the *Seroja* Tropical Cyclone when normal conditions have wave heights from 0.75 to 2.5 meters then increases significantly from 2.0 to 7.0 meters. On the other hand, data on extreme weather occurrences in the form of rain show intensities above 100mm/day in all the cyclones studied. In addition, this intensity occurred three days before the cyclone grew. Then, an increase in rainfall began to be seen and the extreme weather gradually decreased when the tropical cyclone started to disappear. Understanding this happening, it is necessary to boost vigilance when tropical cyclones happen, especially for sea transportation and for users of maritime activities. This is because the effects arising from tropical cyclones are extremely risky. With an analysis of the occurrence of this tropical cyclone, it is expected that it can be a notice and an alert for the maritime world including maintaining maritime safety and security in general.

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