Mapping Atmospheric – Ocean Parameter Risk Index based on Meteorological Review to Support the Operational Work of Sea Toll Road Program

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Abstract: Indonesia is the largest archipelagic state in the world, two-third of its total area is a marine region. It is such enlightenment when the current government is aware of Indonesia's marine potential and prioritizes policies that support maritime transport through a concept known as the Sea Toll Road project. According to this project, safety factors such as environmental hazards need to be put under serious consideration. ECMWF ERA-Interim Reanalysis for wind data, daily rainfall data from TRMM, and WaveWatch III model data in 2013 have been adjusted to determine and assess the safety risk threshold for each parameter. This information is used as the basic data for mapping spatial distribution of wind, rainfall, and wave height profile in each period of the months. The atmospheric–ocean parameter risk index map shows that in the active monsoon period, the closed seawater over Indonesia generally tends to possess a higher risk level of sailing, especially for a barge. During Asian Monsoon, high-risk levels exist at the range index 5-7 which occurs on the north part of the Indonesian sea while in the Australian monsoon period that index happens on the south part of the Indonesian sea. Therefore, this risk index within the map is important to be used as a sailing warning for supporting the safety of the Sea Toll Road project and to reduce the accident rates during shipping activities.

1 INTRODUCTION

As the largest archipelagic country in the world, Indonesia has a wider marine region than its land area. Based on the United Nations Convention on the Law of the Sea (UNCLOS) 1982, Indonesia's total marine area is around 5.9 million km2, with coastline reaching up to 95,161 km, second-longest after Canada (Lasabuda et al., 2013). Realizing this potential sector, the government has issued several policies to actualize Indonesia's vision to become the world's maritime axis. The concept of "Sea Toll" was later introduced and became one of the most limelight policies in recent years.

The concept of Sea Toll Road is likely to become the most awaited policies, especially for those who work in the marine transportation sector. Nearly 99.5% of the movement of the world's economy is done through the sea (Kadarisman et al., 2016). During hustle and bustle discussion about the program, shipping safety has become an important issue that has not received much attention. Based on historical data, natural factors, both in the form of bad weather and high waves, have the most influence on the incidence of ship accidents (Rahman et al., 2017). Furthermore, research related to the condition of the Indonesian sea and its relationship to safety has not been widely studied. Whereas, knowing the condition of the sea waters is the main requirement for ship's crew and fishermen before they go to sea.

Some of the atmospheric-ocean parameters that affect shipping safety are surface wind conditions, rainfall, and wave height. Heavy rainfall causes visibility to decrease, while the direction and velocity of wind have a strong relation to the variation of wave height. Weather factors such as wind and waves are very important for ship movement, especially related to their safety (Pranowo et al., 2012; Wicaksana et al., 2015).

Based on the explanation above, this research aims to analyze three atmospheric-ocean parameters to provide information about the risk profile of sailing safety as an effort to support the Sea Toll Road program. Recent research conducted in Surabaya-

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Makassar shipping trajectory has concluded that weather patterns, essentially for rainfall, the height of the sea waves, and the speed of the ocean currents could be used as fundamental elements to recognize maritime weather patterns to determine the safety of the ship (Lutfiana and Tirono, 2013). Therefore, the final objective of this research is mapping the sea-atmosphere parameter risk profile index of the Indonesian marine region, so that areas that have potential bad weather in certain months of normal years can be informed as a warning to the public. In the future, this map is expected to reduce the number of transportation accidents over the Indonesian sea. The success of this study will give good impacts in terms of practical meteorology and contribute some benefits for infrastructure development, economy, mobility, and most importantly shipping safety.

2 DATA AND METHODOLOGY

This study was conducted over the Indonesian sea and used three atmospheric – ocean parameters, such as wave height, rainfall intensity, wind direction, and wind speed. The data then analyzed to obtain atmospheric – ocean parameter risk index. The research period in this study was determined in 2013 since it was the latest normal year, a year without any atmospheric – ocean disturbances.

2.1 ECMWF Reanalysis Wind Data

One of the products of the European Centre for Medium-Range Weather Forecast (ECMWF) model is reanalysis data. ERA-Interim reanalysis data used in this study consists of u-wind component (zonal) and v-wind component (meridional), also the parameters of wind speed at 10 m altitudes. ECMWF reanalysis data is numerical prediction data with the highest verification level in the world. In addition, wind model data of ECMWF showed a relatively similar pattern with wind data obtained from observation by BMKG in September 2008 (Krisdiantoro, 2012).

2.2 WaveWatch III Model Data

Based on WMO guidelines (1998), for wave climatology analysis, data can be obtained from two main sources, namely: (a) measurement and observation results, and (b) estimation results based on wind data (wave hindcast). Data from measurement and observation at sea are generally very limited and not continuous. Therefore, in this study, WaveWatch III model is used to obtain significant wave height data. The WaveWatch III model is a third generation (III) model developed by National Centers for Environmental Prediction (NCEP). This system has a global domain with the resolution of 50 km. Suratno (1997) shows that the results of verification between WaveWatch III model with vessel data obtained a correlation above 0.6.

Based on research conducted by Kurniawan et al. (2012), wave characteristics over the Indonesian sea have patterns associated with monsoonal wind cycles. The pattern of monthly variations in high-wave and high-frequency waves in most of the Indonesian territorial marine areas has two peaks that occurred in the Asian monsoon period (December-January-February (DJF)) and Australia monsoon period (June-July-August (JJA)).

2.3 TRMM Rainfall Data

TRMM rainfall data is a joint space mission between the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) designed to monitor and study rainfall variations over the tropical region. Bowman (2015) showed that when comparing land-based gauges with TRMM, the correlations are substantially increased by time-averaging the gauge data between the two measurements for gauge-average periods of about 2 to 10 h. Maximum correlation coefficients are in the range of 0.6 to 0.7. Moreover, Schumacher and Houze (2000) assessed the performance of TRMM by comparing the data with Kwajalein oceanic validation radar, it showed that the data agree well within the range of sensitivity of the precipitation radar.

2.4 Analysis Process

Three atmospheric – ocean parameters data then spatially processed using the Grid Analysis and Display System (GrADS) to understand the monthly characteristics of each parameter. TRMM daily rainfall data (mm/day) is available in .nc format and then plotted as the monthly average. The GrADS provides programming tools and an execution environment to ease program development for the grid (Cooper et al., 2004).

The increasing frequency of maritime transportation accidents in Indonesia has recently become increasingly alarming. Several accidents occurred in the sea, both sinking of ships and collisions between ships (Lutfiana and Tirono, 2013). One of the factors that can cause collisions between ships is the decrease of visibility due to rain events occurred over the region. Categorization of rainfall data was based on the press release of the National Agency for Meteorology Climatology and Geophysics (2010), as shown in Table 1.

Table 1: Criteria for rainfall intensity in Indonesia.

Category	Rainfall intensity (mm/day)
Light	5 – 20
Moderate	20 – 50
Heavy	50 – 100
Very Heavy	>100

The wind parameter is also categorized based on its risk level on shipping safety, especially over a barge (Table 2). The barge was selected to be a standard model of transportation modes since the progress in infrastructure development in the last two years has been increased significantly. Many barges serve the distribution of infrastructure materials such as cement, stone, and sand for infrastructure development. Barge business also uplifted significantly, followed by an increase in demand for coal shipments (Simorangkir, 2017). Surface wind data is the result of ECMWF models in *.nc* format and then processed to determine the monthly characteristics of wind direction and speed using GrADS.

Table 2: Criteria for wind parameter in Indonesia.

Category	Wind speed (knots)
Very low	<7
Low	7 – 10
Moderate	10 – 16
High	>16

Table 2 shows that if the wind speed is less than 7 knots, it possesses a very low-risk level for the shipping activities of the barge. If the wind speed reaches 7 – 10 knots, then the cruise risk level is relatively low. Meanwhile, if the wind speed ranges from 10 – 16 knots, the cruise risk level is categorized to be moderate. Whereas if the wind speed reaches more than 16 knots, the risk level of the shipping activities is said to be high.

Significant wave height data used in this study is available in *.nc* format. The data is then processed to understand the monthly characteristics of the wave height using GrADS. In marine practical meteorology, significant wave height terminology is often used to express ocean wave height. Based on data records, significant wave height is defined as the average height of 1/3 of the highest waves, which is equivalent to the wave height of visual observations (WMO, 1998). The

Table 3: Criteria for significant wave height in Indonesia.

Category	Wave height (meter)
Very low	<0.75
Low	0.75 – 1.0
Moderate	1.0 – 1.5
High	>1.5

equation for calculating the significant wave height is explained by Wara (2019) as follows:

$$H_{\frac{1}{3}} > \frac{1}{\frac{1}{3}N}\sum_{m=1}^{\frac{1}{3}N} H_m \tag{1}$$

Interpretation of wave height variations towards shipping safety based on information provided by the Indonesian Agency of Meteorology Climatology and Geophysics. Table 3 shows that the wave height which is less than 0.75 m has a very low-risk level (safe) for the shipping activities of the barge. If the wave height reaches 0.75 - 1.0 m, then the cruise risk level is relatively low. Meanwhile, if the wave height ranges from 1 - 1.5 m, the fishermen should be vigilant because the risk level of sailing is said to be moderate. Whereas if the wave height reaches more than 1.5 m, the risk level of the sailing activities is said to be high and fishermen are generally advised not to go to sea. In every coordinate, the value of each parameter is then categorized into 4 index values and summarized in Table 4.

Table 4: Quantification of index values on each parameter.

Parameter	Parameter value	Index Value
Wave height	< 0.75 m	1
	0.75 – 1.0 m	2
	1.0 – 1.5 m	3
	> 1.5 m	4
Wind speed	< 7 knots	1
	7 – 10 knots	2
	10 – 16 knots	3
	> 16 knots	4
Rainfall intensity	5 – 20 mm/day	1
	20 – 50 mm/day	2
	50 – 100 mm/day	3
	>100 mm/day	4

After defining the index value for each parameter, the risk profile of atmospheric-ocean parameters is then determined based on the sum of these three parameters, with the maximum total index for these parameters is 12 and the minimum value is 1. The determination of the criteria will be adjusted according to Table 5 below:

Table 5: Risk index determination based on total index.

No	Total	Risk profile
1	1 – 3	Low
2	4 – 6	Moderate
3	7 – 9	High
4	10 – 12	Very high

Risk profile naming is adjusted to the risk matrix product issued by BMKG (2018). The total index is the value obtained from the sum of the index values of the three parameters used. This value is then used as a basis for determining the atmospheric-ocean parameter risk index as information about the risk profile of weather conditions on shipping safety. The total index value or herein after referred to as the risk matrix level is mapped using Q-Geographic Information System (QGIS) to analyse the monthly risk profile of shipping security. QGIS is open-source software that lets users visualize, question, analyze, and interpret geographical data (Shaira, et al., 2020).

3 MONTHLY AVERAGE OF ATMOSPHERIC – OCEAN CONDITIONS

3.1 Wind Profile over Indonesian Sea

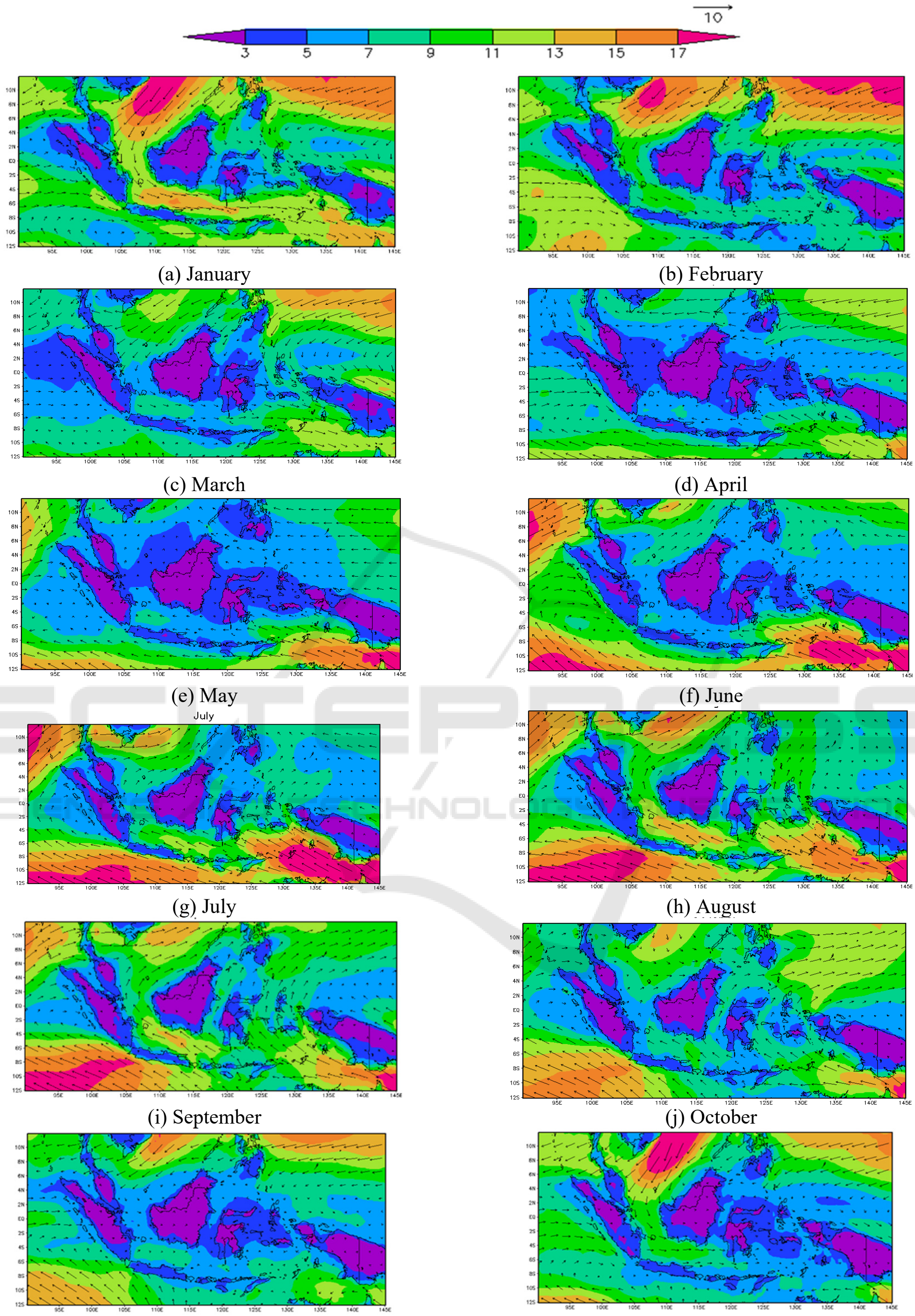
The wind parameter is a wave generator factor in the free ocean. Kisnarti (2012) in her research on meteorological-oceanography studies for shipping operations said that wind is the main generator of waves. The wind that blows above the surface of the water will move its energy into the water. Wind speed will cause stress on the surface of the water which is initially calm and will be disturbed and there will be ripples or waves above the surface of the water. If the wind speed increases, the ripples become larger and when the wind blows continuously a wave will eventually form. The longer and the stronger the wind blows, the larger the waves form. The height and period of the wave generated by the wind are influenced by wind speed, wind duration, wind direction, and fetch (Wibisono, 2005).

Generally, the characteristics of waves in Indonesian sea waters have patterns associated with the monsoonal wind cycle. The waters of the high seas that are directly related to the oceans generally have higher sea waves compared to closed waters between islands. In the Asian monsoon period (DJF) in 2013 (Figure 1), wind speed generally starts to increase in December and gets stronger in January then begins to weaker in February. January possesses the strongest wind distributed around the South China Sea and the Pacific Ocean with velocity ranges from 13 up to more than 17 knots. This condition is really dangerous for a barge to sail. The wind speed around Karimata Strait ranges from 9 – 13 knots, becomes stronger when the seawater flows over the Java Sea region, and again decreases over the Banda Sea, Arafura Sea, and the Timor Sea along with the general direction flow of the wind that from Asia to Australia region. The weakest wind region was distributed around Makassar Strait and the Molucca Sea with ranges from 5 – 7 knots.

3.2 Significant Wave Height Variability

Waves are an important factor in marine meteorological information services (WMO, 2001). Frequent high waves can cause disruption on fishing activities, inter-island sea transportation which can impact lives, scarcity of foodstuffs on several islands, and various types of work due to constrained supply of construction materials. In comparison to other types of waves, waves due to wind are the most dominant waves occurring at sea level, both in terms of frequency of occurrence and energy (Hutabarat and Evans, 2008). The existence of waves due to wind on the sea surface affects almost all marine activities and therefore information about these waves is an important part of marine meteorological information services.

Kurniawan et al. (2012) stated that the characteristics of the wave over the Indonesian sea have patterns associated with monsoonal cycles. Figure 2 shows the variation of the significant wave from month to month in 2013. In the Asian monsoon period, the wave height around the strait region in the Indonesian sea commonly ranges from 0 – 1 meter. In January 2013, the wave height around the Java Sea, some parts of Banda Sea, and Timor and Arafura Sea can reach up to 1 – 1.5 meter, which is dangerous for a barge to sail. When it comes to the transition period of MAM, Indonesian seas dominantly calm because the wave height was around 0 – 0.75 m. However, some parts of Arafura and Timor Sea start to increase



(a) January (b) February
(c) March (d) April
(e) May (f) June
(g) July (h) August
(i) September (j) October
(k) November (l) December

Figure 1: Wind speed and direction monthly profile over Indonesian sea in 2013.

in height from March to May. The maximum wave height reaches around this marine area in May 2013. Once Australian monsoon comes, this maximum wave height areas expand up to Banda Sea with a value of around 1 – 2 meters. The maximum areas of high wave in Australian period occur in July 2013, and the wave height starts to decrease in August. However, there is an increase in wave height around Java Sea in August. The second transition phase period shifted the area of high wave around South China Sea and spacious marine area over Pacific Ocean. The maximum wave height happens in November with a value around 1.25 – 1.5 meters. In December 2013, where Asian monsoon dominates, the wave height over South China Sea region reaches its maximum up to 2.5 meters and remains stable until the next month.

Kisnarti (2012) explained that the high-wave month period occurs in January, February, July, and August and therefore, categorized as dangerous months of the year. The monthly pattern of high-wave variations and high-frequency waves in most of Indonesia's territorial sea has two peaks, which occurred in DJF period and JJA period. Marine areas that relate to the South China Sea (Karimata Strait, Natuna Sea) and the Pacific Ocean (Sulawesi Sea, Maluku Sea, and the marine areas on the northern Papua), the Java Sea, Flores Sea, and Makassar Strait reach their highest peaks in the Asian monsoon period.

In contrast, the Banda Sea, Arafura Sea, and marine areas around Indian Ocean (Timor Sea, Savu Sea) reach their highest peaks in the Australian monsoon period. The study also explains that the high-wave prone areas during Asian monsoon period were wider than when Australian monsoon period. Whereas in the transition season between the two monsoons most of Indonesia's waters are not categorized as dangerous areas.

3.3 Rainfall Intensity Variation over Indonesian Sea

Rainfall is one of the weather and climate elements that have a dominant influence in the tropics such as Indonesia, compared to other elements. Therefore, understanding the characteristics of rainfall, both its variability and extreme conditions is very important to recognize the characteristics in order to support human activities (Harijono, S. W. B., dan Junaeni, I., 2008), including assisting shipping activities.

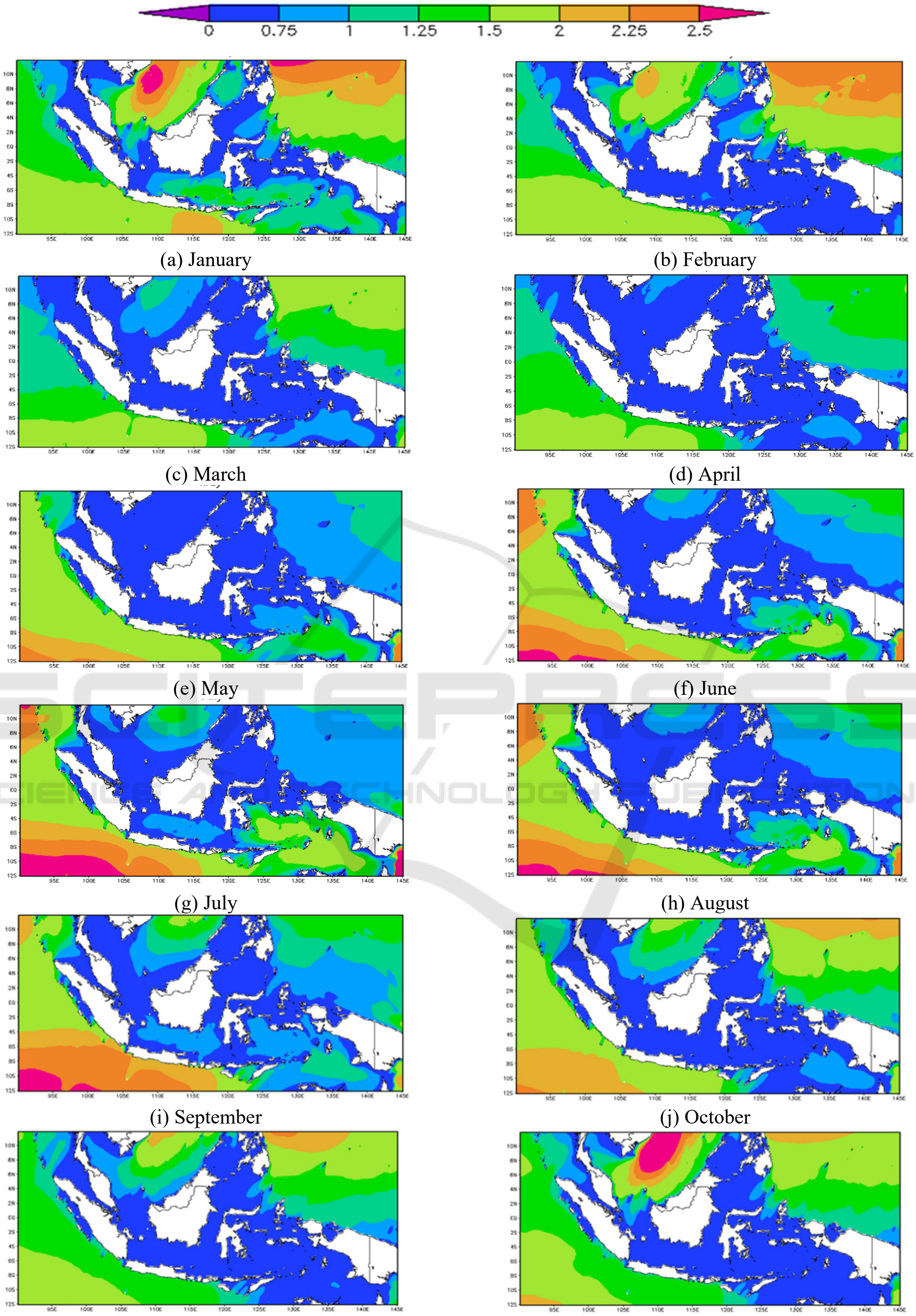
Lutfiana and Tirono (2013) further studies show that rainfall has a significant influence in determining the safety levels of shipping activities along Surabaya - Makassar shipping lane.

The area where the rainfall intensity is quite high is located around Java Sea and some part of Pacific Ocean in January with a value around 10 – 40 mm/day, while in February the highest rainfall intensity region was around the small part of the South China Sea with a value around 15 – 30 mm/day. Based on categorization made by Indonesian Agency of Meteorology Climatology and Geophysics, this categorized as moderate rain, however, until now there is no particular rainfall categorization (impact-based forecast) for each type of marine transportation. Therefore, we assume that moderate rain can cause a hazard for the barge to sail.

In the next months of the first transition period (MAM), rainfall intensity over Indonesian sea was quite lower than the intensity overland region. In March 2013, rainfall intensity in all parts of Indonesian sea ranges from 5 – 15 mm/day. While it starts to slightly increase April and May. In Australian monsoon period, rainfall intensity tends to be slightly higher over marine regions than land areas. Its distribution was varied and random, but it starts to significantly decrease in August, especially in the south part of Indonesia. This condition persists until couple of months later. Rainfall intensity on the south part of Indonesia, both marine and land areas, significantly decrease in the second transition period, except in November. Rainfall intensity increases significantly in December 2013, especially on the north part of Indonesian seas such as South China Sea, Java Sea, and some part of Indian Ocean near Sumatra islands.

3.4 Atmospheric – Ocean Parameter Risk Index Variation

Three atmospheric–ocean parameters have been evaluated and quantified based on Table 4 in order to get the risk index of sailing safety over the Indonesian sea (Table 5). This total index can be used as a reference for the government, especially the Ministry of Transportation, to assess the safest sea lanes and inform the public. When the total index reaches a value between 1 and 3, then a barge has a low-risk level to sail over the Indonesian sea, in other words, it is safe for a barge to sail over a marine region that possesses the index value within the range. While if the total index value ranges from 4–6, the risk level is said to be moderate, it means that a barge must be vigilant during sailing over this region. If the total index value ranges from 7–9, the risk level is said to be high for a barge to sail. It is recommended for a



(a) January (b) February
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(k) November (l) December

Figure 2: Month to month variation wave height in meter over Indonesian sea region in 2013.

barge not to sail over these sea lanes. Meanwhile, if the total index value reaches up to 10 – 12, the risk level is said to be very high, which means it is really dangerous for a barge to sail over the region. But figure 4 shows that the conditions where the risk level is categorized very high rarely happen over closed sea waters regions over Indonesia in normal years. Therefore, it assumes that this condition can occur when a cyclone or other atmospheric–ocean disturbance phenomenon happened.

Based on the risk index variation map in January (Figure 4a), the risk level is very high over the South China Sea and some parts of Pacific and Indian Ocean near Sumatra and the south part of Java Island. The high-risk level region occurred around Java Sea, a small fraction of Banda, Arafura, and Timor Sea. While moderate-risk level region mostly occurred over Karimata Strait. The lowest risk level region was located around Makassar Strait, Molucca Sea, and the northern part of Banda Sea. This low-risk level region is commonly located over small sections of closed sea waters between some islands surround it as a great barrier and obstacle when the wind blows over it.

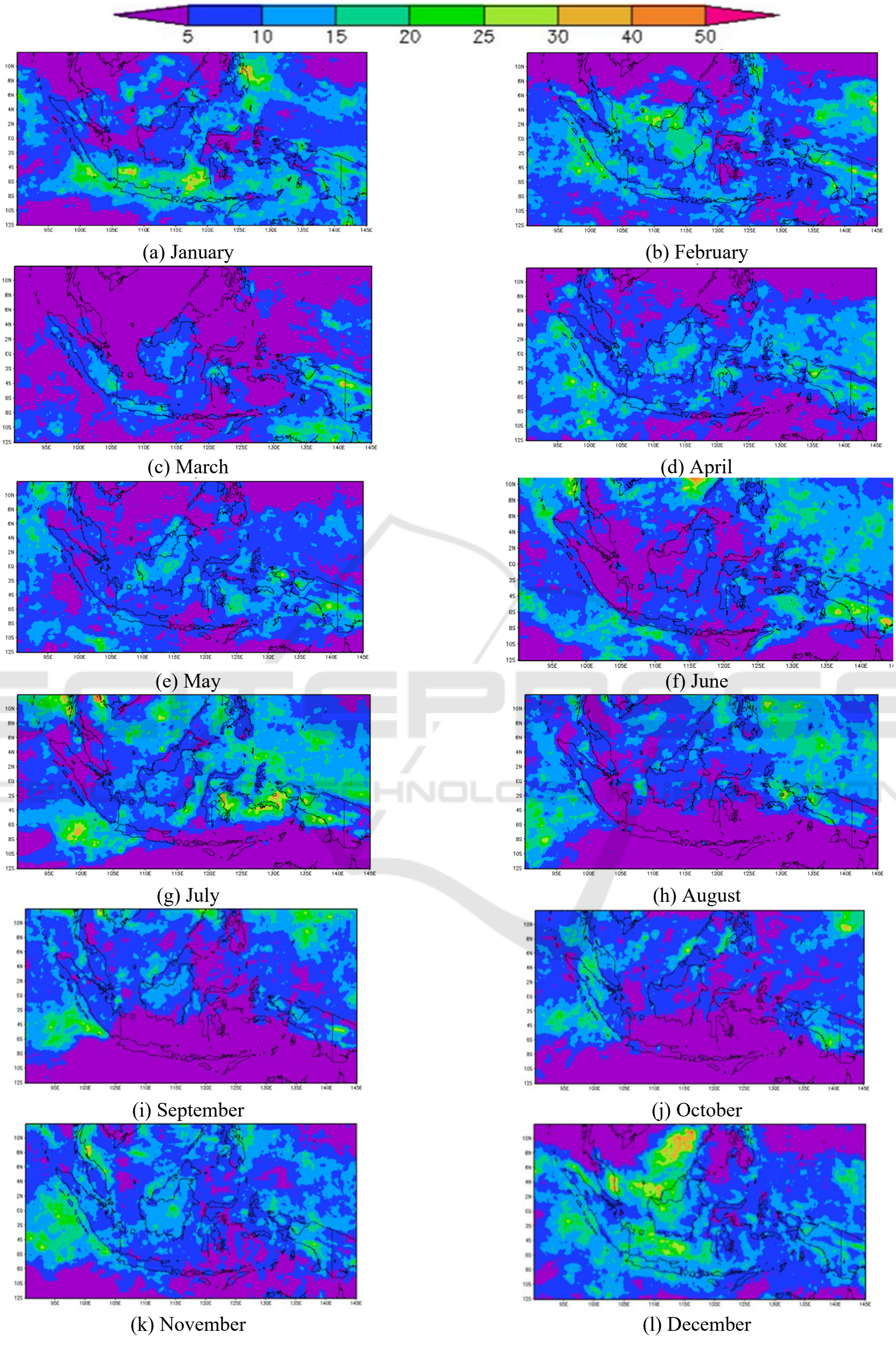
In February, the risk shipping level over the Indonesian sea was mostly moderate, such as over Karimata Strait, Java Sea, Banda Sea, Arafura Sea, and Celebes Sea. The other region among closed seawater regions over Indonesia possesses a lower risk level, such as along some parts of Makassar Strait and some part of Molucca Sea. While, since it is in the Asian monsoon period, the risk level over South China Sea and along the Pacific Ocean is categorized as very dangerous. The atmospheric–ocean parameter risk level variability tends to get lower in March, low-risk level region expands over several regions, including Karimata Strait, a small fraction of Java Sea, Makassar Strait, and Molucca Sea. While the rest areas possess a moderate risk level of sailing. In April, the lower risk level region tends to get wider and covers almost all part of closed sea waters in Indonesia. The high-level risk region starts to occur over Indian Ocean, it moves from Pacific Sea in DJF period to Indian Ocean as it is approaching JJA period. In the last month of the first transition phase period of MAM, the atmospheric–ocean parameter risk index over the southern part of Indonesian sea start to increase significantly, especially over Indian Ocean near Australia.

In Australian monsoon period in June, the atmospheric–ocean parameter risk level elevated, especially over Arafura, Banda, and Timor Sea along with the strengthening of the Australian Monsoon. This high-risk level region then expands and reaches its maximum in July 2013 and starts to slightly decrease in August. In the second transition period in September, the atmospheric–ocean parameter risk level generally moderate over all parts of Indonesian sea, except in a small fraction of Celebes Sea, Makassar Strait, and Molucca Sea. In October, the lower risk level region starts to get wider and covers almost all parts of the Indonesian sea. While, both Pacific and Indian Oceans possess moderate to high-risk levels. In the last month of SON period, November, the low-risk level region became wider and covered all parts of the closed seawater in Indonesia. This condition changed significantly in December when the Asian monsoon began to be strengthened. The high-risk level region observes over the dominant part of South China Sea and along the Pacific Ocean. Karimata Strait and Java Sea possess moderate risk level of sailing safety, while the other generally tend to have the low-risk level of sailing safety.

4 SUMMARY AND CONCLUSION

The wind speed over Indonesia has a distinctive pattern where the strongest wind region is commonly located near the ocean, both in Pacific and Indian ocean, while it starts to decrease as it approaches the Indonesia sea region, closed waters between the islands. The significant wave height pattern generally follows the surface wind pattern as it is the wave generator factor in the free ocean. Generally, the characteristics of waves in Indonesian sea waters have patterns associated with the monsoonal wind cycle. In Asian monsoon period (DJF), wind speed generally, starts to increase in December and gets stronger in January but then tends to weaken in February. January possesses the strongest wind distributed around South China Sea and Pacific Ocean with velocity ranges from 13 up to more than 17 knots.

Compared to wind profile and wave height variation, rainfall intensity pattern possesses a higher variability, both in land and marine region. In Asian monsoon period, the rainfall intensity reaches its maximum in December 2013 with heavy rainfall areas distributed around the South China Sea and Java Sea region with range values from 20–50 mm/day. It starts to decrease in January, more often significant in February. In transition periods, rainfall intensity tends to have a higher value over land area rather than over marine region. In Australian monsoon period, rainfall intensity tends to be slightly higher over marine regions than land areas. Its distribution was varied and random, but it started to significantly decrease in



(a) January (b) February (c) March (d) April (e) May (f) June (g) July (h) August (i) September (j) October (k) November (l) December

Figure 3: Rainfall intensity (mm/day) variability over Indonesian sea from month to month in 2013.

Table 6: Summary of Indonesia's atmospheric-ocean risk index.

Rank	Marine Region	Risk Value	Month
1	Indian Ocean to the Southwestof Java	10	July
2	Indian Ocean to the South ofJava	9	August
3	Arafura Sea	8	June
4	Banda Sea	7	August
5	Indian Ocean to the Southwest of Java	6	November
6	Western Indian Ocean of Sumatera	5	March
7	Seram Sea	4	February
8	Maluku Sea	3	February
9	Indian Ocean to the East of Kupang	2	February
10	Makassar Strait	1	May

August, especially in the south part of Indonesia. This condition persists until a couple of months later. Rainfall intensity on the south part of Indonesia, both marine and land areas, significantly decreased in the second transition period, except in November. Rainfall intensity increased significantly in December, the beginning period of Asian monsoon, especially on the north part of Indonesian seas such as South China Sea, Java Sea, and some part of Indian Ocean near Sumatra Island.

As summarised in Table 6, the atmospheric–ocean parameter risk index map shows that in the active monsoon period, the closed seawater over Indonesia generally tends to possess a higher risk level of sailing. In Asian monsoon, the marine area that possesses moderate – high-risk levels commonly located on the northern part of Indonesian seas, such as South China Sea and Java Sea. While in the Australian monsoon period, the marine areas that possess moderate to the high-risk level generally observe on the southern part of Indonesian seas, such as over Banda Sea, Arafura, and Timor Sea. Several marine areas in Indonesia possess low – moderate risk levels of sailing throughout the normal year, such as Makassar Strait, Molucca, and Celebes Sea. For further research, this atmospheric-ocean parameter risk index can be improved to gain variations of the results by using a longer time series of data under the consideration of another climate phenomenon, such as El Nino and La Nina. Enhancing collaboration between agencies is also required to support this project and to obtain some feedback from many stakeholders.

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