The surface wind regimes on the northeast coastal of Kalimantan during 2016-2018

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Abstract. This research aims to investigate the wind patterns in Northeast coastal of Kalimantan Island, known to border the western part of the Sulawesi Sea. Furthermore, the temporal wind patterns were examined based on the 2016-2018 recording data on Tarakan Island. The distribution of wind direction as well as speed were further analysed to obtain the monthly and seasonal wind pattern. The results show pattern complexity in the research area indicated by shifting in the monthly and seasonal wind resultant. This shift is particularly from the north, on instances where the Asian Monsoon is active, and conversely from the south at the Australian Monsoon peak. Meanwhile, during the transition period between monsoons, the wind blows weakly from various directions. However, the monsoon index value does not meet the criteria for the monsoon wind due to the influence of the sea breeze from the Sulawesi Sea throughout the year. Further analysis shows that the complexity of the local wind pattern is formed by sea breeze which is intertwined with monsoon winds.

1. Introduction
The unique configurations in the Indonesian archipelago prompted Klaus Wyrtki to write a monumental Naga Report after collecting information for three years. Wyrtki (1961) disclosed fundamental knowledge, particularly regarding the monsoon dynamics, surface and deep water circulation, sea and atmosphere exchange, as well as water circulation in the south-eastern Asian deep-sea basins, especially for those around Indonesia [1]. The tropical islands are identified as ideal monsoon areas due to the geographical position (between Asia and Australia). Furthermore, Ramage (1968) reported on the significance role of that tropicals "Maritime Continent" in the atmospheric circulation at global scales [2].

The interaction between land, water bodies and the atmosphere triggers variability in climatology. These interactions occur on local, regional, continental as well as global scales. The wind is generated by change in atmospheric temperature and pressure in the atmosphere, due to solar radiation, energy distribution, cloud shielding, and other related dynamics [3]. The Indonesian wind system are influenced on a continental level by Asian and Australian monsoon winds, with periodically reversed directions. This phenomenon is caused by thermal variation between continents and oceans [3–6].
Wyrtki (1961) stated the Asian Monsoon is fully formed in January, while the Southern (Australian) counterpart peaks during July and August [1].

The atmospheric circulation affects the ocean currents motion to a depth of about 200 m [3]. Hence, an understanding of these patterns is applicable in marine and fisheries studies, including marine ecosystem dynamics with biological resources, fishing operation design, coastal and offshore engineering, littoral vulnerability in small islands as well as socio-economic aspects influenced by extreme wind and wave seasons. Therefore, this study aims to determine the wind pattern through monthly and seasonal wind speed and direction distribution models. The discussion focuses on the wind temporal variability on the Kalimantan northeastern coast regarding the two monsoon periods.

2. Material and Method

The data utilized include the hourly wind speeds and directions from 2016 to 2018, measured by the Meteorology and Geophysics Agency (BMG) station, Juwata Airport, Tarakan. Meanwhile, these details were obtained from www.rp5.ru. Figure 1 shows the geographical position of this island city along the northeast coast of Kalimantan and directly adjacent to the Sulawesi Sea.

Figure 1. Research area in the Tarakan Island, North Kalimantan, Indonesia

Subsequently, WRPLOT View™ Version 8.0.2 (Lakes Environment, 2018) was used to calculate the wind statistics for each month and season. Wind speed classified in accordance with the Beaufort equivalent scale’s by WMO (1998; 2018) [7–9]. Furthermore, wind speed and direction are depicted by resultants of the vector components $v_x$ and $v_y$ to the reference point. Where, $v_x$ is parallel to the x axis (east (-) to west (+)), and $v_y$ to the y axis (north (-) south (+)).

Furthermore, the windrose, histogram, frequency count and distribution both monthly and seasonal were generated by the WRPLOT View™. Windrose shows wind vector frequency according to the
wind speed class from sixteen cardinal direction. This sixteen cardinal directions system were used in order to obtain more detailed variations, as compared to using four or eight. Seasonal grouping including DJF (December - February) Asian Monsoon, MAM (March - May) transition I, JJA (June - August) Australian Monsoon and SON (September - November) transition II periods. Subsequently, the monsoonal properties were determined based on the Khromov (1957) index, as shown below [10].

\[ I_{kh} = \frac{(F_{Jan} + F'_{July})}{2} \]  

Where;

- \( I_{kh} \): Monsoon Khromov Index
- \( F_{Jan} \): The total number of dominant wind frequencies in January
- \( F'_{July} \): The total number of dominant wind frequencies in July

The monsoon index is generally calculated based on the dominant wind direction of 8 cardinal directions or per 45 division. This calculation is based on the cumulative wind frequency of 2 dominant directions adjacent in January and July, based on the 16 parts demarcation or per 22.5. Khromov (1957) determined the Monsoon Index value to be at least 40% of the total wind frequency in affected areas [10].

3. Results and Discussion

3.1. Monthly Wind Variability

Figure 2 shows the direction and speed of monthly winds plotted on a rose chart. These are individually indicated by the resultant vector line during 2016-2018.
Figure 2 shows the monthly wind pattern analysis result, indicating a shift in the dominant wind direction. This specifically transited from North West to North East between January and March, with vector resultants ranging from 22 - 35%. However, there was a wide variation from April to June, followed with decreased of the resultant wind frequency (6 – 14%). Meanwhile 25 - 33% was reported for July and August, with Southern origin. In addition, a variation between South West and North West was recorded from September to December. The present result is in line with Ogawa and Ogawa et al., (2019) statement that the resultant or average wind vector can be differ from the observed wind [11].

3.2. Seasonal Wind Variability
The seasonal patterns related to the effects of monsoonal cycle are determined using a windrose chart created according to seasonal periods, as shown in Figure 3. In addition, DJF represents the Asian Monsoon period, MAM denotes Transition I, featuring the period between the end of the Asian and the start of the Australian Monsoon. Moreover, JJA represents Australian Monsoon, and finally, SON indicates Transition II, which separates the end of the Australian and the arrival of the next Asian Monsoon.
Figure 3. Grouped windrose based on seasonal periods (a) DJF, (b) MAM, (c) JJA, and (d) SON.

Figure 3 shows the dominant wind from the North West direction, in the DJF period. The wind vector resultant shows that average wind come from North (12°) which made up 22% contribution. The wind tends to weaken during the MAM period and blows from various directions with low resultant values. This decline indicates a shift in patterns during the Transition I Season. Furthermore, when the Australian Monsoon came in the JJA period, the dominant wind blow from the south. This period was also marked by elevated wind frequency from the direction recorded, and is estimated to contribute about 24% of the total recorded winds. Meanwhile, in the second transitional season, the wind speed decreases again and comes from various directions.

Figure 2 and Figure 3 denote consistent presences of Sea Breeze all year, as an archetype or original pattern of local wind system extending from the Sulawesi Sea to the Kalimantan mainland. Furthermore, these sea breeze motion was attributed to the differences in air pressure between both regions, and is assumed to continuously facilitate circulation.
3.3. The Monsoonal Wind Influence

The difference in temperature and air pressure between the Asian continent to the north and the Australian continent to the south triggers wind movements across the equator [3]. This periodic reversal of the dominant direction forms the monsoon cycle on both continents, as well as the Maritime region, assumed to be the path of atmospheric circulation. The monsoon area is defined as a region with dominant wind reversal, of at least 120° between January and July. Several researchers have proposed a Monsoon Index, to delimit the Monsoons region [12–14]. Khromov (1957) determined that the Monsoonal region had an Index value of at least 40 [10]. Furthermore, Ramage (1971) added wind strength criteria to improve the Khromov’s Monsoon Index [15].

Figures 2a and 2g show a difference of 164° between the resultant wind direction observed in January and July. Therefore, the research area is estimated to have met the criteria of dominant wind reversal, resulting from the influence of monsoon.

Table 1. A comparison of the percentage wind distribution frequency between January and July.

| Frequency (%) | N   | NNE  | NE   | ENE  | E    | ESE  | SE   | SSE  | S    | SSW  | SW   | WSW  | W    | WNW  | NW   | NNW  |
|--------------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| January      | 8.9 | 5.29 | 4.32 | 9.13 | 15.62| 2.65 | 2.16 | 1.44 | 5.05 | 3.36 | 3.36 | 5.05 | 7.7  | 5.05 | 10.58| 10.34|
| July         | 2.65| 1.77 | 1.54 | 4.63 | 11.04| 6.84 | 2.65 | 6.62 | 17   | 7.73 | 7.29 | 5.96 | 8.6  | 6.18 | 4.64 | 4.86 |

\[ I_{Kh} = 21.98 \]

The Monsoon Index of current research area was unable to meet the Khromov criteria by 40% (Table 1). However, the entire Indonesian Archipelago is included in the Monsoon area delineation by [15]. Aldrian (2008) states that there is no index that can accurately define monsoon characteristics for the Indonesian region [3]. Aldrian (2008) continued that this is due to the presence of several types of monsoonal on the maritime continent and local variations which significantly affect climate variability such as topographic and orographic characteristics [3]. Furthermore, this variability is caused by the influence of the Madden-Julian Oscillation (MJO), Cold Surges, and other Synoptic Weather Systems [5,16–18]. The monsoon variability in the Indonesian Archipelago as a response when the Asian Monsoon and Australian Monsoon is active has a distinctive character that is why it is called the "Maritime Continent Monsoon" [5,16–18].

3.4. Local Sea Breeze System

Figures 3 and 4 shows the presences of Sea Breeze consistently blowing from Sulawesi Sea to Kalimantan mainland in all periods. This phenomenon was due to the difference in pressure between land and the adjacent ocean [19–23]. Furthermore, this results imply that the Sea Breeze Circulation forms a Prevailing Winds which is the archetype of the wind system on the studied area. The highest frequency of Sea Breeze was recorded during the Transition I (Figure 4). On the other hand, the Land Breeze blows from various directions, this is in line with the statement of Aldrian (2008), Yamanaka (2016), and Alfahmi (2019), that the winds over the land gets the orographic influence of the land [3,24,25].
Figure 4. The comparison of the percentage frequency distribution of wind direction in the 2016-2018 DJF (Asian Monsoon), MAM (Transition I), JJA (Asian Monsoon), and SON (Transition II) periods. Elliptic Shade Area shows the Sea Breeze (A) and the relevance between local Sea Breeze to the Asian Monsoon (B) and Australian Monsoon (C).

The presence of the Sea Breeze during all the periods was shown by the shaded elliptic area A in Figure 4. The consistent Sea Breeze Circulation in Indonesia also reported by [19,20,24–26]. The Asian Monsoon active during DJF Periods produced a heightened wind frequency from the North West to the North, as portrayed in the shaded elliptic area B. This surge was accompanied by a slight increase in the Sea Breeze frequency compared to the preceding SON period. The Elliptic shade area C show the ability for Australian Monsoon wind from the South to reduce the frequency of Sea Breeze from east. Figure 3 and 4 demonstrates that the dominant winds are associated with the Asian, as well as the Australian Monsoon, while in both Transition experienced weaker wind force. The Asian Monsoon northwest wind deflection by Sea Breeze also indicated in Figure 3a resulting the north as average wind vector. Conversely when the Australian Monsoon is active in July, dominant wind are blow from the south. These circumstance were consistent with the findings about the average Northeast Kalimantan winds in January, possibly originating from the North-Northeast (NNE) and South-West-Southwest (SSW) directions in July postulated by [17,27–29].

This wind pattern are known to influence various aspects of the community life on the North-eastern Kalimantan Coast. In addition, Tarakan was determined to be a territory where air and city ports represent the major gateways connecting remote areas in North Kalimantan with other cities throughout Indonesia and abroad. However, accessibility to these transportation modes between regions are limited due to the situation of the city as an island. Furthermore, the primary means of movement including speedboats operated along the coast and rivers, small planes used to access the inland areas, and fishing activities are all susceptible and limited by bad weather conditions during the wind and wave seasons. Therefore, further investigations are required on other areas affected by the existence of seasonal patterns comprising capture fisheries, agriculture, livestock, transportation, maritime, and pertinent components of disaster mitigation planning including forest fires commonly associated with the Australian Monsoon.
In addition, climatological researches are needed to perform the analysis of integrated synoptic data for numerous meteorological stations and several variables. These studies are crucial as several factors including the Tropospheric Biennial Oscillation (TBO), Indian Ocean Dipole Mode, Madden Julian Oscillation (MJO), El Niño – Southern Oscillation (ENSO), and Cold Surges cause variabilities in the Maritime Continent Monsoon, especially on the Island of Borneo [3,5,28,30–32]. Therefore, the presence of a more reliable and specific weather model useful for the regional development planning in the future is anticipated. Also, meteorological modelling research can be integrated with research in other fields to answer 23 priority research questions in Asia in order to support the achievement of "sustainable environmental quality” [33]

4. Conclusions
This study investigates wind regime from the northeast coast of Kalimantan, based on the analysis of wind vectors, in order to reveal the dynamics and variability. The results showed the existence of complex patterns, encompassing the combination of archetype and monsoonal patterns. The Sea Breeze as an archetype of local wind system are induced by differential pressure between Sulawesi sea and the Kalimantan mainland. This local Sea Breeze seasonally influenced by the monsoonal cycle, both system then intertwined to make a complex pattern of wind regime. Further research is needed to study synoptic patterns with a longer recording range in combination with other climatological variables. Also, it is important to conduct studies integrated with other fields. This is expected to define the relationship between the with fisheries, agriculture, and maritime, as well as the disaster mitigation aspects due to climate and extreme weather.

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