The wave characteristics in Natuna Sea and its adjacent for naval operation base purposes

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Abstract. Natuna Sea is one economy strategic outer area, which connected into archipelagic international sea lanes (ALKI I). The research area is in that area using two specifics observation Naval base stations: (South) Dabo Singkep and (North) Ranai. Wave characteristics are needed to be conducting a secure the naval operation cruises. The statistical analysis is carried out using 2016 ECMWF 6 hourly datasets with 14 km grid spatial resolution. The variable of significant wave height (SWH), period and wave direction has been analyzed by monthly-yearly averages. Maximum SWH during rough wave period is range of 5.1 m (January) and 2.3 m (February). The minimum SWH is range of 0.2 m (April) and 0.1 m (July). The predominantly wave direction at Dabo Singkep is coming from southeast (135°; mostly in July), and at Ranai is coming from the northeast (45°; mostly in January). During the rough wave period, it is highly recommended using the KRI warship with length > 82 m and high hull > 2.3 m for surveillance cruise in the southern part of Natuna Sea. While in the northern part, would be needed KRI with a length > 146 m, and the high hull > 4.8 m.

1. Introduction
Land, water, and air are dimensions of space used to implement military operations. Every space dimension has parameters that can determine the success of a military operation. Parameters that affect military operations in the sea is an attribute of seawater, sea surface behavior, marine topography and representative naval ramifications. The uppermost layer of seawater is eternally dynamic in response to ocean climate interaction [1].

One important parameter of the hydrodynamic is wave. Wave is a mechanism of up and down sea surface in perpendicular which happened in a moment until it reaches equilibrium [2]. Sea surface height difference can be generated by some sources such as the wind, earth plate activity, due to the movement of the ship, tidal pumping and ocean currents [3]. In this study we are focusing on the wind waves.

Waves energy will be considered as a nuisance when used as a parameter in the field of navigation, port, coastal and offshore engineering [4]. Therefore, it is very important to study hydrodynamics for management and its control [5]. So that energy resulting from ocean waves do not give a loss in human life.

Nowadays, the maritime economy is one of the priority target sectors by Indonesian Government for the next 25 years [6]. Indonesia should take the sea as a media liaison between the islands. Indonesia have 16.056 named and coordinated islands [7]. The connectivity among those islands is expected to be
optimalized, so that all development sectors can be well distributed. One important role is attainment with protecting stability and security in Indonesian Seas.

Various ways can be conducted to protect stability and security of Indonesian Seas. One of those, by providing information of ocean wave characteristics. It can be used as a reference of how to choose the class's warship (KRI) for surveillance cruise. Because protect cruise safety and maritime security is the responsibility of The Indonesian Government [8].

Indonesian archipelagic setting among the two oceans will have various and unique wave characteristics. The appropriate management system can reduce risk level of KRI accidents during the military operation, if the determination of KRI class is adjusted to the wave characteristics. In this study, we are using 5 (five) class of KRI.

2. Materials and methods

This study focuses on the waves generated by the wind, where there will be three different physical processes and eventually known as wind sea and swell [9]. The location of wind sources, fetch, wind speed, long wind blow and wind direction are parameters that can affect the height, direction and wave period.

The study area is located in Natuna Waters (table 1). Dataset used is significant wave height (SWH), mean wave direction (MWD) and mean wave period (MWP) throughout 2016, downloaded from ECMWF (European Centre for Medium-range Weather Forecasts) website with spatial resolution 14 km x 14 km (0.125° x 0.125°) and resolution temporal 6 hours [10]. Mean wave direction is defined using the meteorological convention that zero means "coming from the north" and 90 "coming from the east" [11]. Data is calculated monthly and seasonal average to see the characteristics [8].

| Table 1. Classification of wave directions. |
|--------------------------------------------|
| Wave direction    | Class degree (°) |
| North            | 337.5 – 22.5     |
| Northeast        | 22.5 – 67.5      |
| East             | 67.5 – 112.5     |
| Southeast        | 112.5 – 157.5    |
| South            | 157.5 – 202.5    |
| Southwest        | 202.5 – 247.5    |
| West             | 247.5 – 292.5    |
| Northwest        | 292.5 – 337.5    |

Ocean Data View (ODV) Software is employed to visualize ocean wave’s propagations (2D SWH model), as a tool for analyze wave characteristics and its form in the research area. WRPLOT software is applied to visualize wave directions, in the form of a rose diagram, with 5 (six) colors as classification of wave velocity. Classifications of wave direction and velocity in WRPLOT are grouped in the table 1 and 2, respectively.

| Table 2. Classification of wave velocity. |
|------------------------------------------|
| Color   | Velocity (ms⁻¹) |
| Orange  | ≥ 16            |
| Yellow  | 12 – 16         |
| Light green | 8 – 12   |
| Dark green | 4 – 8      |
| Blue    | 0 – 4           |

The research location is determined from the data station (●). Station 1 (♦) is located in the working area of the Dabo Singkep Navy Base around meeting ALKI 1, with branch 1A connecting the Singapore Strait to geographic coordinates 00° 45’ 00” N 106° 7’ 30” E. Station 2 (▲) is located in the working area of Ranai Navy Base around the boundary line of the Indonesian continental
shelf in geographic coordinates 6° 30’ 00” N 109° 15’ 00” E [12]. From geographical view, station 2 has more open sea space than station 1 flanked by Kalimantan Island (east) and Bintan Island (west), see figure 1.

Ocean waves are the physical form of sea water where still water level (SWL) experience up and down movement resemble sinusoidal line so that it has wave height, wavelength and sea surface fluctuation with wave direction and wave velocity that affects the motion of water particles. Ocean waves have some parameters such as wave height (H), wavelength (L), wave velocity (C), wave period (T), wave amplitude (a) and water surface fluctuation (η). Significant wave height (Hs) is obtained from average of 1/3rd (one-third) highest individual wave height that occurs during a specific time period [13], see Figure 2.

Analyzing wave height can not be equated for all areas. The depth is a parameter must be considered. Wave characteristics will be affected by the friction of water particles with the seabed, when the depth is relatively shallow. The motion of water particles does not erode the seabed when the depth is relatively deep. Based on The Indonesian navigation chart number 354, station 1 has average depth of 200 meters [14]. The chart number 360 shows station 2 has average depth of 50 meters [15]. The length and wave velocity are determined using the equation of Airy wave theory [16], see equation (1) and (2). Wave
period data can be used to compute the wavelength value (equation 2), which then used to compute the wave velocity value (equation 1).

\[ C = L \frac{T}{T} = gT \left(2\pi \right)^2 = 1.56 x T \]  

\[ L = gT^2 \left(2\pi \right)^2 = 1.56 x T^2 \]  

Explanation: \( L \): wavelength (m), \( g \): Acceleration of gravity (9.8 ms\(^{-2}\)), \( T \): wave period (s), \( C \): wave velocity (ms\(^{-1}\)), \( \pi \): 3.14.

The effect of ocean wave motion to ship stability will cause two motion types i.e translational motion and rotation motion [17]. According to them, motion forward/backward (surge), right/left side (sway) and up/down (lifted) is translation motion; while rotational motion is rotating motion to axis line as rotation shaft (figure 3).

![Figure 3. Effects of ocean wave motion on ship stability [17].](image)

The safest motion KRI to ocean waves when navigating is surge translation motion and pitch rotation motion [18, 19]. Based on those motions, the line of water length of the ship (LWL) become a parameter to determine wavelength limit and hull height of prow (HH) is used as the parameter to determine wave height limit. The work flow for analyzing a wave characteristics is presented in figure 4.

![Figure 4. Flowchart analysis of wave characteristics for KRI recommendations.](image)
3. Results and discussion

3.1. Significant wave height characteristics
In February 7, 2016 from 18.00 UTC to 24.00 UTC, maximum significant wave height in station 1 reached 2.3 meters. Minimum significant wave height reached 0.1 meters, occurred in July 01, 2016 from 06.00 UTC to 12.00 UTC. High wave dominant occurred on February and low wave dominant occurred on April (figure 5).

![Figure 5. Significant wave height mareogram of 6 hours average in station 1.](image)

In January 25, 2016, from 12.00 UTC to 18.00 UTC, maximum significant wave height in station 2 reached 5.1 meters. Minimum significant wave height reached 0.2 meters, occurred in April 14, 2016, from 18.00 UTC to 24.00 UTC. High wave dominant occurred in February and low wave dominant occurred in April (figure 6).

![Figure 6. Significant wave height mareogram of 6 hours average in station 2.](image)
3.2. Significant wave height propagation

The global ocean is strongly dominated by swell waves spreading away from the influence of the wind zone [20]. Based on the form of significant wave height contour lines can be known the location of influence of the wind zone and the direction of its propagation. The change in direction of the propagation of significant wave height influenced by the state of geographic and hydrographic.

Analyzes of wave propagation patterns are grouped into four seasons [21]. Natuna People distinguish four seasons based on wind direction i.e. north season on November to February, East season on March to June, the south season in July and August, west season on September and October [22]. In northern season, wave height reaches the maximum height and bad weather occurred in Natuna Sea [23]. The wind can influence the length and significant wave height that occurs in Indonesian Seas [19].

The 2D model of significant wave height in Natuna Waters has 4 (four) propagation’s colors to help analyzing wave heights (figure 7). Wave direction dominant changes from northeast to southwest during North season and East season. During North season, in February 7, 2016, from 18.00 UTC to 24.00 UTC in station 1 has maximum significant wave height reached 2.3 meters (green) and wave propagation direction came from Natuna Besar Islands (25°) with wave height ranged 2.3 to 3.2 meters (green). The area between Anambas Islands and Natuna Besar Islands has significant wave height ranged 3.3 to 3.4 meters (green). Wave propagation direction in station 2 came from the northeast (27°) toward Natuna Besar Islands with wave height ranged 3.3 to 4.6 meters (green-yellow).

During North season, in January 25, 2016, from 12.00 UTC to 18.00 UTC, in station 2 has maximum significant wave height reached 5.1 meters. The wave propagation direction came from the northeast (30°), toward Natuna Besar Islands, with significant wave height ranged of 2.9 to 5.1 meters (red-
yellow-green). The area between Natuna Besar Islands and Anambas Islands has significant wave height ranged of 2.5 and 2.7 meters (green). Wave propagation direction, in station 1, is came from Natuna Besar Islands (34°), with significant wave height ranged of 1.5 to 2.1 meters (green-blue).

Minimum significant wave height in Natuna Sea in every season has almost evenly. It might because of wind speed is getting slower, and cannot generate significant waves. During South season, in 2016, station 1 has minimum significant wave height. Station 2 has minimum significant wave height during East season. Because in Natuna Waters experienced dry season where the wind blows from southern hemisphere toward northern hemisphere [24].

In July 1, 2016, from 06.00 UTC to 12.00 UTC, station 1 has minimum significant wave height reached 0.1 meters (light purple), with wave propagation direction is came from southeast (134°). The area between Natuna Besar Islands and Anambas Islands has significant wave height ranged 0.2 meters (purple). Station 2 has significant wave height reached 0.3 meters (dark purple), with wave propagation direction is came from the southwest (231°).

In April 14, 2016, from 18.00 UTC to 24.00 UTC, station 2 has minimum significant wave height reached 0.2 meters (purple), with wave propagation direction is came from southeast (161°). The area between Natuna Besar Islands and Anambas Islands has significant wave height reached 0.3 meters (dark purple). Station 1 has significant wave height reached 0.2 meters (purple), with wave propagation direction is came from the south.

In general, Indonesia territory based on geographical location has two monsoons i.e. east monsoon and west monsoon [25, 26]. East monsoon (April - September) brings a dry season causing by the wind blows from Australian Continent to Asian Continent [27]. West monsoon (October - March) brings a rainy season causing the wind blows from Asian Continent to Australian Continent [28]. In general, west monsoon a lot of sea transportation vehicles undergo accident due to bad weather condition [29]. Bad sea weather is induced by extreme wind including its ocean waves [30]. That is why very important to analyzing wave’s characteristic, due to forecasting, to get the information about the safest periods for surveillance cruise activities. The results can also used as reference of decisions taken by policy (stake) holders to manage their marine zonation [31].

In Natuna sea, based on wave roses diagram in station 1 and station 2, during the north and east seasons are dominated by west monsoon. Wave propagation direction is came from the South China Sea. The highest mean wave velocity, ranging from 12 to 16 ms⁻¹, occurs ofently during the north season in station 2 (figure 8).

![Figure 8. Wave rose chart of seasonal average in station 1 (top row) and station 2 (bottom row).](image-url)
Monthly wave variations can be showed by computing a monthly average data of SWH [18]. Station 1 has range maximum SWH in February ranged of 0.4 to 2.3 meters. In April and May, minimum SWH has range of 0.2 - 0.7 meters. In January, February and December, wavelength is over 80 meters. Maximum wavelength reached 86.3 meters is founded in January. In general, during January-April and November - December, wave is propagate from northeren toward south hemisphere. Maximum wave velocity (8.6 ms$^{-1}$) is found in February (table 3).

### Table 3. Monthly average of wave characteristics in station 1.

|       | Height (m) | Length (m) | Direction (°) | Velocity (ms$^{-1}$) |
|-------|------------|------------|---------------|----------------------|
| January| 0.4 – 1.7 | 24.8 – 86.3 | 41        | 8.3                 |
| February| 0.4 – 2.3 | 21.2 – 82.1 | 31        | 8.6                 |
| March  | 0.4 – 1.7 | 18.9 – 61.4 | 39        | 7.5                 |
| April  | 0.2 – 0.7 | 11.5 – 47.8 | 62        | 6.5                 |
| May    | 0.2 – 0.7 | 14.2 – 50.3 | 100       | 6.5                 |
| June   | 0.2 – 1.4 | 11.8 – 44.7 | 164       | 5.8                 |
| July   | 0.3 – 2.3 | 12.8 – 35.4 | 159       | 5.7                 |
| August | 0.2 – 1   | 13.3 – 36.5 | 162       | 6.2                 |
| September | 0.2 – 0.9 | 15.6 – 50.3 | 207       | 6.5                 |
| October| 0.2 – 0.8 | 13.3 – 47.7 | 240       | 6.3                 |
| November | 0.3 – 1.2 | 19.4 – 73.3 | 353       | 7.7                 |
| December | 0.3 – 1.6 | 22.3 – 80.1 | 349       | 8                   |

Thousands of islands setting, in Indonesian seas, then creating various fetches, which is influences wind movement characteristic [32]. In general, monthly wave average of station 1 is lower than station 2. It might because of the station 2 is located more open sea than station 1. Then, Station 2 has significant wave heights over 3 meters, during January - March, and also in December. Beware of wave height in January because maximum significant wave height reached 5.1 meters. In April has minimum range significant wave height ranged 0.2 to 1.2 meters. But if we have a look into the wavelength characteristic, it is only December has a wavelength over 170 meters, with maximum length of 171.7 meters. The wave moves from the South China Sea to Karimata Straits in January - May, and also November – December. Maximum wave velocity (12.3 ms$^{-1}$) is found in December (table 4).

### Table 4. Monthly average of wave characteristics in station 2.

|       | Height (m) | Length (m) | Direction (°) | Velocity (ms$^{-1}$) |
|-------|------------|------------|---------------|----------------------|
| January| 0.7 – 5.1  | 32.3 – 168.4 | 45        | 10.3                 |
| February| 0.8 – 4.9 | 30.8 – 146.8 | 45        | 11.3                 |
| March  | 0.5 – 3.3  | 24.9 – 105.6 | 45        | 9.4                  |
| April  | 0.2 – 1.2  | 16 – 64.5    | 54        | 7.2                  |
| May    | 0.3 – 1.7  | 21 – 83.3    | 25        | 7.8                  |
| June   | 0.3 – 1.2  | 13.5 – 42.4  | 234       | 6.7                  |
| July   | 0.2 – 1.4  | 16.5 – 44.3  | 232       | 6.6                  |
| August | 0.4 – 2.1  | 23.3 – 66.1  | 242       | 7.9                  |
| September | 0.5 – 1.6 | 24.7 – 70.8  | 268       | 7.9                  |
| October| 0.4 – 1.6  | 21 – 110     | 289       | 8.4                  |
| November | 0.5 – 2.3 | 33.6 – 147.1 | 41        | 11.2                 |
| December | 0.8 – 3.3 | 53.1 – 171.7 | 33        | 12.3                 |
3.3. Analysis of wave height and length versus KRI warship dimension
Dabo Singkep Naval Base and Ranai Naval Base is work unit of the Naval Main Base (Lantamal) IV under Indonesian Navy Western Fleet (Koarmabar), which have type and class of KRI warship in table 5.

| Type       | Class          | LWL (m) | HH (m) |
|------------|----------------|---------|--------|
| Frosch I   | Teluk Sibolga  | 82.5    | 10     |
| Parchim    | Wiratno        | 75.2    | 5.3    |
| FPB 57 NAV IV | Barakuda    | 54.4    | 2.8    |
| Kondor II  | Pulau Romang   | 53      | 3.2    |
| KCR-40     | Kujang         | 40      | 2.7    |

The wave energy will be considered as the intrusion, when used as parameter of navigation [33]. The calm waves will intensively increase cruise activities. However, if strong winds and high waves then it is expected to have kind of an information of the proper KRI warship dimension to keep the safety during cruises. These information is also needed for public sea water transportations [18].

Analysis of wave height and length of the (war-) ships are important role for Naval policy holders concerned at sea, i.e. for cruise management strategy, and for marine infrastructure development [31]. Wave height data is used to determine hull height (HH) of KRI prow from sea water line (LWL). If prow hull of KRI higher than wave height, then ship equipment on the open deck is safe from overtopping waves. Wavelength data is also used to determine line water length of KRI. For minimize pitch rotation motion of KRI, the line water length KRI must be longer than the wavelength. Pitch rotation motion of KRI will influence the accuracy of cannon fire during cruise. The worst scenario (damaging and drown of KRI warship) will be happened when wave height and length higher than LWL and HH, in respectively.

3.4. Recommendation
For those who sail in ALKI I, a warning (SWH > 3 m; ~80% susceptibility) should be given during December - January to every ship before sailing [34]. Based on 2016 datasets, high waves often occur in February, then the recommended KRI, who will carry out surveillance cruise at station 1, is to have prow hull height more than 2.3 meters, and ship water line length more than 82 meters. For KRI, who will carry out surveillance cruise at station 2, is recommended to have prow hull height more than 4.8 meters, and ship water line length more than 146 meters. An example, KRI Kujang is not recommended to carry out surveillance cruise at station 2 because every month is formed wavelength exceeds line water length of class’s KRI Kujang (see Table 8 and compared with Table 3 & 4).

4. Conclusion
In station 1, all class’s KRI should be alert to ocean waves that occurred in January because wavelength exceeds ship line water length and wave height reached 1.7 meters so that it causes pitch rotation motion of KRI. In station 2, all class’s KRI should be alert to ocean waves that occurred in the north season. And for class’s KRI Kujang is not recommended to carry out surveillance cruise at station 2 because every month is formed wavelength exceeds line water length of class’s KRI Kujang. Without losses of material and personnel than a military operation is declared successful. The success of military operation at sea must be supported by information on ocean wave characteristics. It might because of high waves and bad weather will threats a military operation at sea.

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