Analysis of seasonal variability of wave height in Makassar Strait

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Abstract. This study was conducted to examine spatially the seasonal variability of sea wave characteristics in the Makassar Strait waters by utilizing the third generation wave model, MIKE 21 Spectral Wave Model. The study was conducted by observing seasonal variability of sea wave height in Makassar Strait waters for 10 years. The data used are wind data predicted by ECMWF every 6 hours during the period 2006 - 2015 as the main input of wave energy generation. The domain model is adjusted to the wind configuration in a uniform grid size of 5°x 5° which is considered to be sufficient to represent the bathymetry of the Makassar Strait waters with location limits of 1,00°LU - 3,98°LS and 116,15°BT - 120,30°BT and 15 stations. Based on the results of the study, showed that high waves occur in the west season which tends to follow the monsoonal pattern according to the local climate type. The maximum significant wave height tends to occur in the western, central and southern waters of the Makassar Strait with an average observed in the middle of the year in the June, July and August periods (east monsoon). For the study of coastal waters, maximum wave height fluctuations tend to be uniform.

1. Introduction

The dynamics of ocean currents and waves in Indonesian waters generally follow a monsoonal wind pattern, especially in the surface layer where wind is the main energy source. If there is a monsoonal wind pattern deviation, the seasonal order is disrupted, resulting in wave climate change [1][2][3]. In some global studies it also shows that extreme wind conditions have an impact on the resulting wave which is also extreme [4]. Increasing wind speed is the main factor that contributes to increasing wave height [5].

Based on the characteristics of space, the waters of the Makassar Strait are waters which separate two of the five major islands in Indonesia, namely Kalimantan Island on the west side and Sulawesi Island on the east side. These waters also connect the Sulawesi Sea at the mouth of the northern strait and the waters of the Java Sea at the mouth of the southern strait. The condition of bathymetry in these waters can be broadly divided into two parts. On the east side, approaching the island of Sulawesi, the strait waters are categorized as deep waters because they have depths of more than 2000 m and on the western side of the strait, approaching the east coast of Borneo Island, categorized as shallow waters with a depth of less than 200 m [6].

For all the time, Makassar Strait waters are used for shipping and fishing activities. The intended shipping activities can be shipping by passenger and shipping vessels for the distribution of goods or...
materials from Kalimantan to Sulawesi or vice versa, which indicates inter-island interactions. Republic of Indonesia Government Regulation No. 37 of 2002 stipulates that the waters of the Makassar Strait are included in one of the three of Alur Laut Kepulauan Indonesian (ALKI) used as international shipping traffic. These waters are included in the ALKI II route with the Sulawesi Sea, Makassar Strait, Flores Strait and Lombok Strait to the Indian Ocean, and vice versa.

Some official warnings from the BMKG website state that there is a potential for high waves in the waters of the Makassar Strait which reaches 2-3 meters. Information on the potential for high waves usually occurs in the western season (December, January, February) and in the eastern season around July and August. Examples in some cases of transporting coal from Balikpapan (Kalimantan) to Sulawesi, which if the distribution was carried out to coincide in those months, were hampered due to high waves. High waves can occur in the middle and south waters of the Makassar Strait. While in normal circumstances, the wave height in Balikpapan waters (western Makassar Strait), ranges from 0.5 - 0.75 m and in the central and southern parts of the Makassar Strait, ranging from 0.75 - 1.25 m. Wave height potential that exceeds normal conditions can endanger shipping activities.

In this study, a study of the characteristics of ocean waves in the Makassar Strait will be carried out to predict wave events that are affected by climate variability. The importance of a review of the variability of ocean wave characteristics is needed in the management of sea transportation flow paths. According to data from the Directorate of Sea and Coast Guard of the Directorate General of Sea Transportation, from ship accident data in 2009 [7], it was shown that the incidence of ship accidents in Indonesian waters around 33% was caused by natural conditions in this case the ocean waves. Thus, if the seasonal pattern of wave characteristics in a waters is well understood it can reduce the risk of marine transportation accidents by avoiding shipping lanes known to have potential hazards.

The study will focus on the study of wave characteristics offshore waters associated with the monsoon climate. The study approach was carried out by utilizing a third generation wave prediction model, MIKE 21 SW [8]. Several other third-generation wave models are WAVEWATCH-III [9][10] and WAM Cycle-4 [11][12][13][14][15].

Several studies conducted for ocean wave analysis related to the use of satellite imagery altimetry, show that satellite data has a better coverage for wave observation in offshore waters, compared to coastal or nearshore waters [5]. For the observation of sea waves in coastal waters, it would be better if done by measuring in situ [15][16].

This research is expected to support the study of the characteristics of sea waves in the Makassar Strait waters based on climate variability. Utilization of wind data for predicting wave height in Indonesian waters is more widely applied because the availability of observation data in the oceans is still limited. Thus the coverage includes observations of wave characteristics over a long period of time using time series data over an interval of 10 years, and can also be used for the purposes of observing trends in wave conditions. Wave characteristics relate to the character or average pattern of representative waves over a given time scale. This study aims to assess the seasonal variability of wave characteristics in the Makassar Strait waters for the last 10 years. The results of this study are expected to be used as a reference in the management of maritime activities using marine transportation as an early detection system for the opportunities for high waves to occur in the Makassar Strait.

2. Research methods
2.1 Ocean wave forecasting
Ocean wave prediction is mostly done to obtain an overview of sea conditions and dynamics through numerical approaches. Ocean wave modelling concept refers to the concept of spectral energy equilibrium which forms the wave field as a function of time and space [11][12][17]. Generally, the spectral energy equations in third-generation wave models such as the WAM Model [11][12][17] and the MIKE21 SW Model [8], use the energy source equation $S$, as a superposition of the source functions representing physical phenomena in nature, expressed as:
\[ \frac{\partial F}{\partial t} + (\cos \phi)^{-1} \frac{\partial}{\partial \phi} (\phi \cos \phi F) + \frac{\partial}{\partial \lambda} (\dot{\lambda} F) + \frac{\partial}{\partial \theta} (\dot{\theta} F) = S \]  

(1)

or simply written in relation:

\[ \frac{\partial F(f, \theta)}{\partial t} = -\nabla (C_g F(f, \theta)) + \frac{\partial \nabla \theta C_g F(f, \theta)}{\partial \theta} + S \]  

(2)

Where:

\[ \nabla (C_g F(f, \theta)) \] expresses energy propagation with group velocity \( C_g \)

\[ \frac{\partial \nabla \theta C_g F(f, \theta)}{\partial \theta} \] states the effect of wave refraction due to changes in bathymetry

The function S is expressed as a source and sink function, formulated as:

\[ S = S_{in} + S_{nl} + S_{ds} + S_{bot} + S_{surf} \]  

(3)

In equation (3), \( S_{in} \) = wind energy input term, \( S_{nl} \) = nonlinear interaction between spectral components, \( S_{ds} \) = white-capping term, \( S_{bot} \) = interaction dissipation term with the base and \( S_{surf} \) = wave energy dissipation term when propagating to shallow areas.

2.2 Research sites

The selection of research locations is based on the reason that these waters are often used for shipping that connects between provinces in the process of distributing goods, marine transportation activities (passenger ships) and as a fishing area. In accordance with the Government Regulation of the Republic of Indonesia No. 37 of 2002, the waters of the Makassar Strait were designated as the Indonesian Archipelago Sea Channel (ALKI) II, which is also an alternative route for international navigation traffic.

The study area can be seen in Figure 1 with the boundaries of 1,00\(^0\) N - 3,98\(^0\) S and 116,15\(^0\) E - 120,30\(^0\) E. Determination of the location of the observation station and the model output station for the wave characteristic study was chosen with the consideration that the Makassar Strait waters are waters that are often used in marine transportation activities both nationally and internationally and are also used as fisheries management areas. Therefore, the selection of stations refers to the shipping route in accordance with the Government Regulation of the Republic of Indonesia No. 37 of 2002 for the Indonesian Archipelago Sea Channel (ALKI) II and several other observation stations.

The bathymetry contours of the Makassar Strait waters in this study were made based on the bathymetry map of the Makassar Strait published by the Indonesian Navy's Hydro-Oceanography Service from the map sheets with number 126 (2012), number 127 (2012) and number 128 (2013). The bathymetry map and observation stations can be seen in Figure 1. Station coordinates can be seen in Table 1.

2.3 Data and data processing

The data used are global wind speed and direction data (\( U_{10} \)) 6 hours intervals from the European Center for Medium-range Weather Forecast - ECMWF (http://data-portal.ecmwf.int). Bathymetric
data with a scale of 1: 250,000 from map sheets 126 (2012), 127 (2012) and 128 (2013) are sourced from DISHIDROS TNI - AL Indonesia. This data is used in determining the spatial grid of ocean wave characteristics as well as data from the Seamap for the Makassar Strait, adjusted to the input model format [8]. Data were processed using the MIKE21 Model with full adoption according to the model format. The results of the model are then analyzed according to the objectives to be achieved.

Table 1. Coordinates of Wave Characteristics Output Stations

| No | Station | Latitude | Longitude |
|----|---------|----------|-----------|
| 1. | ALKI II-2 | 00°00'00" | 119°00'00" E |
| 2. | ALKI II-3 | 02°00'00" S | 118°17'00" E |
| 3. | ALKI II-4 | 03°45'20" S | 118°17'00" E |
| 4. | MID-23 | 01°11'00" S | 118°42'00" E |
| 5. | BPN-1 | 01°00'00" S | 118°04'00" E |
| 6. | BPN-2 | 01°33'20" S | 117°01'42" E |
| 7. | TLG-1 | 00°47'00" S | 119°38'00" E |
| 8. | Sta-A | 00°53'00" N | 119°37'00" E |
| 9. | Sta-B | 00°46'00" N | 119°08'00" E |
| 10. | Sta-C | 00°38'48" N | 118°10'37" E |
| 11. | Sta-D | 00°21'50" S | 117°45'35" E |
| 12. | Sta-E | 02°46'30" S | 116°45'00" E |
| 13. | Sta-F | 02°15'40" S | 117°12'25" E |
| 14. | Sta-G | 03°00'55" S | 117°26'33" E |
| 15. | Sta-H | 02°51'12" S | 118°37'42" E |

3. Results and discussion

3.1 Zoning significant wave height based on seasonal variability

It is known that in general the wave height in Indonesian waters varies from month to month, this also applies to the waters of the Makassar Strait. Significant wave heights are presented based on seasonal variability (December, January, February (DJF) = west season; June, July, August (JJA) = east season; March, April, May (MAM) = transitional season I (TS-II) and September, October, November (SON) = transitional season II (TS-II)) (Figure 2).

The maximum significant wave height that occurs in the western season of the DJF period is seen to be high compared to other seasons and applies to almost all stations, with a height between 0.6 - 0.8 m, except at Sta-C and TLG-1 stations. The maximum significant wave height for Sta-C and TLG-1 Stations in the west monsoon, is less than 0.6 m. The lower wave height values at these two locations are related to their position on the coast (TLG-1) and the position in front of the bay (Sta-C) where the wind pressure at these two locations is reduced due to their proximity to the land. In this season, especially over the Makassar Strait waters, the wind tends to blow north to south. In the eastern monsoon period, June-July-August (JJA), the maximum significant wave height tends to be high in almost all stations. The highest maximum significant wave height in the eastern monsoon, greater than 0.8 m, occurs at Sta-D, Sta-E, Sta-F, Sta-G, ALKI II-2, ALKI II-3, ALKI II-4, MID-23, BPN-1 and BPN-2. If it is related to the distribution of wind speed in the Makassar Strait waters in the east season, generally the wind speed is higher when compared to the other three seasons. The wind blows consistently from Australia to Asia across Indonesia. Above the Makassar Strait, the wind tends to blow south to north.

3.2 Trend of significant wave height

To determine significant wave height fluctuations, a trend analysis method was applied with the aim of knowing the trend pattern of changes in the significant monthly mean wave height during the observation period determined based on a simple regression equation with time (months) vs average wave height monthly for 1 decade. The time series of maximum significant wave heights for each month over a period of 10 years (2006-2015) were observed at all stations, indicating that the
maximum significant wave height incidence tends to occur in the western and central parts of the Makassar Strait. The maximum significant wave height during this period, reaching > 1.2 m, was observed in the middle of 2010, to be precise during the eastern monsoon (JJA).

For the monthly average significant wave height that occurs over 10 years based on time series, it shows a negative correlation trend pattern with a small effect value and applies equally to all stations. In that sense, the pattern of fluctuation tendency is not visible and even tends to remain. The monthly pattern of significant wave height conditions averaged for each month for 10 years and compared with the average maximum significant wave height that occurred every month for 10 years, can be seen in Figure 3.
Based on the results displayed at each station, it shows that the maximum average occurrence of significant waves occurs in the eastern monsoon, precisely in July. The average maximum significant wave height that occurred in July during an interval of 10 years (2006 - 2015), was in the range 0.83 - 0.94 m, except at Sta-C Station and TLG-1 Station with a range of 0.65 - 0.74 m. This is related to the position of the station which is located in front of the bay (Sta-C) and coastal waters (TLG-1) where the length of the fetch decreases due to the presence of land, resulting in a reduction in wave crests.

The study of the significant monthly average wave height for 10 years, also shows that the lowest monthly average pattern occurs during the transitional season, precisely in April and November. This incident was observed at all stations. The monthly pattern of significant wave height events for 10 years for all observation stations shows a pattern that tends to follow the monsoon pattern, where the occurrence of high waves tends to occur at two maximum peaks, namely in the west season (DJF) and the east season (JJA) with average wave heights maximum occurred in July. The occurrence of the lowest average monthly wave height is related to wind conditions during the transitional season, where the wind speed and direction are blowing in an inconsistent direction so that the waves are destructive.
Figure 3. Information of Monthly Average Maximum Wave Height (m) and Monthly Average Significant Wave Height (m) for Each Station for 10 Years (2006 – 2015)
4. Conclusion
The results of the monthly maximum significant wave height time series study over a period of 10 years (2006-2015) indicate that the maximum significant wave height incidence tends to occur in the western, central and southern parts of the Makassar Strait. This condition is also supported by the persistence of winds that blow consistently in the same direction with high speed during the east and west monsoons, so that the length of the fetch formed becomes longer and provides an opportunity for high waves to occur. During the 10-year span, the maximum wave height information occurred in 2010, with the average observed occurrence in the middle of the year, precisely in the eastern monsoon (June, July, August), the highest average occurred in July. For the study of coastal waters, the maximum wave height fluctuation tends to be uniform or there is no visible dominant value.

The occurrence of significant wave heights in the waters of the Makassar Strait is more likely to be influenced by wind meteorological factors which show the main pattern of 2 seasons, shown based on the west monsoon period and the east monsoon, predominantly influenced by the monsoonal system according to the local climate type.

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