Ocean wave characteristic in the Sunda Strait using Wave Spectrum Model

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Abstract. The wave characteristics including significant wave height and direction, seas and swell in the Sunda Strait are analyzed seasonally to provide marine weather information. This is crucial for establishing secured marine activities between islands of Sumatera and Java. Ocean wave characteristics in the Sunda Strait are simulated for one year (July 1996–June 1997) by using SWAN numerical model. The ocean wave characteristics in the Sunda Strait are divided into three areas of interest; southern, centre and northern part of the Sunda Strait. Despite a weaker local wind, the maximum significant wave height is captured at the southern part with its height of 2.6 m in November compared to other seasonally months. This is associated with the dominated swell from the Indian Ocean contributes on wave energy toward the Sunda Strait. The 2D spectrum analysis exhibits the monthly wave characteristic at southern part that is dominated by seas along the year and swell propagating from the Indian Ocean to the Sunda Strait during December to February (northwest monsoon), May, and November. Seas and swell at northern part of the Sunda Strait are apprehended weaker compared to other parts of the Sunda Strait due to its location is farther from the Indian Ocean.

1. Introduction
Information on weather and sea condition changes is essential to activities on seas, either for sea transportation activities, fisheries, marine resources exploration, or development in marine sector. Natural factor is responsible for two hundred sixty ship accidents [1]. And among various natural factors, one that greatly influences marine activities is wave, and therefore, in the marine meteorological services, in addition to wind information, wave information is the most important that should exist in marine weather information [1]. Since waves are generated by the wind, the incidence of waves is strongly influenced by the presence of winds on the sea surface [1]. Wave variations in the Indonesian waters are mostly induced by the northwesterly and southeasterly monsoon winds. Some wave variations caused by the monsoon winds are wave height, wave period, wave direction, seas and swell in the waters. In addition, wave characteristics can also be affected by storm events. In spite of minor events of storm in the Indonesian waters, waves formed in areas passed by storms can spread to the Indonesian waters due to its long travel distance before finally breaking [2, 3].

Recent studies of wave characteristics using spectrum models have been conducted [4, 5]. A global study of wave characteristics is discussed by using low resolution of WAM Model; this indicates that the presence of swells spread from high latitudes to equator and the dominance of swell in tropical waters, especially in Indonesia might happen throughout the year [4]. A regional study with domains covering the Indian Ocean, Java Sea, Karimata Strait, and South China Sea found variation of annual and semi-annual monsoons that dominates the wave variability in the South China Sea and Indian Ocean [5]. The goal of this present work is to further examine the characteristics of seas and swell in the Sunda
Strait associated with its interaction to dominated monsoon. Moreover, this present work utilizes a higher resolution of spectrum model to capture wave characteristics in more details. This paper is organized as follows: data and experiment are introduced in section 2, section 3 presents the results and discussion of the study, and the conclusions are given in section 4.

2. Materials and Methods

2.1. Data
This study focuses on the Sunda Strait that shown in figure 1 located at 103°–108° E and 5°–8° S. The domains of research simulation include the Java Sea, Sunda Strait, and Indian Ocean. The wide gap in the southwestern part of the Sunda Strait allows the wave characteristics of the Sunda Strait to experience a great influence from the Indian Ocean at depths of about 1000–2000 m. The narrow gap in the northeastern part between the Sunda Strait and Java Sea has a minor effect to the wave variation in the Sunda Strait. In this study, wind and bathymetry data are applied as model input. The wind field is taken from 10 m above sea level called CCMP (Cross Calibrated Multi Purposed) with a gradient resolution of 0.25° × 0.25° and intervals every six hours. Meanwhile, bathymetry data from GEBCO (Global Bathymetric Chart of Oceans) produced with 1° × 1° resolution [6]. The wave characteristics including wave height, wave direction, seas and swell in the Sunda Strait are studied from simulation data using wave spectrum model SWAN (Simulating Waves Nearshore) for one year (July 1996–June 1997).

2.2. Model experiment
SWAN is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes, and estuaries from given wind, bottom, and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. The model is based on the wave action balance equation with sources and sinks [7, 8]. In this simulation, the used input is wind and bathymetry (water depth), while the effect of current is negligible. The wave propagation process that can be simulated by the SWAN model is propagation of waves, refraction, and shoaling related to the spatial variation of the bottom of the water, and diffraction and reflection by a barrier. Meanwhile, the generation and wave dissipation processes contained in the SWAN are generated by wind, white capping-induced dissipation, and dissipation when the wave breaks due to depth factor, dissipation by basic friction, and nonlinear interactions between waves. The SWAN model has three computational spatial grid options, namely box space grid, curved-linear spatial grid, and unstructured space grid. The computational spectral grid is determined with the minimum frequency and frequency of the rated wave.
as well as the desired frequency resolution. SWAN uses an implicit numerical scheme, so that the accuracy of the model results depends on the time interval.

![Figure 2. Regional domain model and bathymetry profile.](image)

2.3. Design experiment
The simulation of the study area in the Sunda Strait, Indian Ocean and Java Sea is a nested simulation of the regional model. As shown in figure 2, the regional model domains include the South China Sea, Karimata Strait, Java Sea, and Indian Ocean. Regional domain simulations were performed using Empirical Orthogonal Function (EOF) model [5]. The wave simulation in the study area uses boundary conditions obtained from regional model results. The scenario used in this wave simulation is a nonstationary hindcasting simulation. The initial spectrum used in the model is the initial spectrum of Joint North Sea Wave Project (JONSWAP). The physical processes that occur in the simulation are the development of waves, quadruplet nonlinear interactions, and dissipation. The discrete wave propagation in the geographic space uses the BSBT (backward in space and backward in time) scheme.

3. Results and Discussion

3.1. Pattern of wave variability
The ocean wave characteristics in the Sunda Strait are divided into three areas of interest, southern part of the Sunda Strait toward the Indian Ocean (area 1), centre of the Sunda Strait (area 2), and northern part of the Sunda Strait toward the Java Sea (area 3) as illustrated in figure 3. The model results show a linear relationship between the higher of wind speed and the higher of significant wave height (Hs). The direction of wave propagation is strongly influenced by the wind direction. Waves generally move in the direction of the wind, however, in certain part of the Sunda Strait, the significant wave height does not correspond to the wind. This is associated with the narrow shape of the Sunda Strait; limiting the occurrence of the development of wave and the wind-distracted swell that dominate the direction of the wave.

Figure 4 presents spatial patterns of wind variability and significant wave height in the Sunda Strait during northwest monsoon months of December-January-February (DJF). The direction of waves in the Indian Ocean is east-northeast and the significant wave heights in the Indian Ocean reach 0.75 to 1.25 m. In Java Sea, the waves move east-northeast in corresponding with the wind direction. The wave characteristics in area 1 are influenced by the open water of the Indian Ocean which lead the waves propagate to the east (area 1). The propagated waves from the Indian Ocean reach area 2 in February and area 3. The significant wave height is significantly reduced (increased) due to the weakened (strengthened) wind in January (February).
Figure 3. Divided areas in the Sunda Strait.

Figure 4. Averaged (a) wind field (m/s) and (b) significant wave height (m) for December–January–February (DJF).

During the southeast monsoon months of June–July–August (JJA), the significant wave height increases to a maximum value (1.8 m) within a year in August (figure 5). In the Indian Ocean, the significant wave height moves to the northwest in the range of 0.75–1 m. The significant wave height in the Java Sea moves to the west at about 0.5 m. Area 1 is influenced by waves that radiate northward from the Indian Ocean. Propagated wave from the Indian Ocean has a minor influence to area 2 and 3 due to inhibited area from waves coming from the Indian Ocean, in area 2 the wave effect of the Indian Ocean is very weak as the waves do not propagate eastwards into area 2. The influence of waves from the Indian Ocean in area 3 is weaker than in area 2 because the waves from the Indian Ocean do not spread eastward to area 3 and the waters in the narrow area 3 inhibit the propagation of waves from the Indian Ocean entering area 3. In addition, the formation of local wind waves in area 2 and area 3 does not occur due to the narrowness of waters in both areas.

3.2. Wind and wave

Figure 6 exposes three points in the Sunda strait. Wind speed, significant wave height, and maximum significant wave are observed monthly during a year at these three points. Time series of wind and significant wave height are shown in figure 7. It exhibits a good correspondence between both parameters except in certain months, where the significant wave height increases as the wind strengthens
and vice versa, except in November at point 1 when the significant wave height reaches its maximum value. This is associated with a swell propagates from the Indian Ocean that contributes to wave energy. The significant wave height at point 1 is 1.4 m in November with a wind speed of 3 m/s, at point 2 is 0.9 m in February with a wind speed of 4 m/s, and at point 3 is 0.6 m in February with a wind speed of 4 m/s. The minimum significant wave height at the three points occurs in April with values of 0.65 m, 0.25 m, and 0.2 m at point 1, 2, and 3, respectively. In addition to significant wave height, the maximum significant wave height (Hmax) displayed in Figure 8 is also calculated to determine the maximum significant wave height within a year in the Sunda Strait. Hmax in the Sunda Strait reaches about 1.25–2.6 m at point 1, 0.6–1.8 m at point 2, and 0.3 to 1.2 m at point 3. Wind direction is also suggested to play a role in contributing the wave direction (figure 9) within a year, except in January and February at point 1, in November, January, and February at point 2, in November and February at point 3. Again, this is due to swell that propagates from the Indian Ocean into the Sunda Strait.

![Figure 5](image1.png)

**Figure 5.** Same as in figure 4 but for June–July–August (JJA).

![Figure 6](image2.png)

**Figure 6.** Three points in the Sunda Strait.

### 3.3. Wave spectrum

The wave spectrum is also studied at the three predetermined points (figure 6). Through the wave energy spectrum, the characteristics of seas and swell in these waters are analyzed by the peak of dominant energy, dominant direction, and local wind direction. The monthly spectrum at point 1 is illustrated in figure 10 where seas exist throughout the year. In March-November the local wind leads to the northwest and the peak density leads to the north, indicates the existence of seas. Likewise, in December - February
local winds lead to east-southeast and the peak density of energy heads east; leading a swell to exist revealed by the peak density of energy to the north but the local wind actually leads to east-southeast. The wave spectrum in May and November shows high density levels compared to other months and denotes maximum significant wave heights while local winds are weakened in this month. To summarize, seas and swell waves occur simultaneously in December–February, May, and November. The direction of the seas to the east and the swell propagated from the Indian Ocean move north; leading to a distraction of wave direction from its local wind direction (figure 7) in January and February. Figure 11 reveals monthly average spectrum at point 2 where the local wind leads to a density peaks at the similar direction, indicating that seas occur almost throughout the year (from December–February, April–August and October). In addition, swell also exists in December-January illustrated by a peak density of energy that leads north, but local winds lead to the East-Southeast and in March-November where the local wind leads to the northwest, but the peak density of the spectral energy moves north-northeast. Similar to point 1, the results at point 2 show a high energy level of the wave spectrum in May and November and exhibit that seas and swells occur simultaneously in December-January and April-October. Monthly average spectrum at point 3 is presented in figure 12. In December-February and March-October, the wave spectrum moves in corresponding with the local wind results in an existence of seas during a year. Moreover, swell exist in January–March, May, and September-November. As at point 1 and point 2, wave spectrum in May and November at point 3 has a very high peak density of the seas energy and in January-March, May, and September–October seas to the east and swell to the north occur concurrently. Table 1 reveals the direction of the monthly seas and swell at the three points.

![Figure 7](image1.png)

**Figure 7.** Time series of wind and significant wave height at the three points in the Sunda Strait.

![Figure 8](image2.png)

**Figure 8.** As in figure 7, but for wind and maximum significant wave height.
Figure 9. As in figure 7, but for wind and wave direction.

Figure 10. Monthly averaged wave spectrum at point 1

Table 1. Direction of seas and swell at the three points. N = North, NE = Northeast, E = East, SE = Southeast, W = West, NW = Northwest.

|        | D | J | F | M | A | M | J | J | A | S | O | N |
|--------|---|---|---|---|---|---|---|---|---|---|---|---|
| Point 1| Seas | E | E | E | N | N | N | N | N | N | N | N |
|        | Swell | N | N | N | - | - | NW | - | - | - | - | NW |
| Point 2| Seas | E | E | E | - | NW | NW | NW | NW | NW | NW | NW |
|        | Swell | N | N | - | N | N | N | N | N | NE | NE | NE |
| Point 3| Seas | E | SE | SE | NW | W | NW | NW | NW | NW | N | NW |
|        | Swell | - | NE | NE | NE | - | NE | - | - | NE | NE | NE |
4. Conclusion
Despite a weaker local wind, the maximum significant wave height is captured at the southern part of the Sunda Strait with its height of 2.6 m in November compared to other seasonally months. This is associated with the dominated swell from the Indian Ocean that contributes on wave energy toward the Sunda Strait. The 2D spectrum analysis that exhibits the monthly ocean wave characteristic at southern part of the Sunda Strait is dominated by seas along the year and swell propagating from the Indian Ocean to the Sunda Strait during December to February (northwest monsoon), May, and November. Seas and swell characteristics at northern part of the Sunda Strait are apprehended weaker compared to other parts of the Sunda Strait due to its location that is farther from the Indian Ocean.

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