Wave Characteristics in Natuna Waters during Typhoon Hagibis Event

I Ardiansyah1, N S Ningsih2*, R Rachmayani2

1Study Program of Earth Sciences, Faculty of Earth Sciences and Technology, Bandung Institute of Technology
2Research Group of Oceanography, Faculty of Earth Sciences and Technology, Bandung Institute of Technology

*Corresponding author: nining@fitb.itb.ac.id

Abstract. Significant Wave Height (SWH) in Natuna Waters (NW) has been simulated during Typhoon Hagibis (TH) event in the periods of 20th – 27th November 2007 in South China Sea (SCS) by using Simulating WAVE Nearshore (SWAN) model with 1/24th spatial resolution. The 1/4° wind data obtained from Cross-Calibrated Multi-Platform (CCMP) and 1/120th bathymetry data derived from General Bathymetry Chart of the Ocean (GEBCO) were used as model input. The open boundary values for SWAN simulation were obtained from WAVEWATCH-III (WW3) results provided by Indonesian Geospatial Information Agency (BIG). In this current study, it was found that the TH had an impact on swell propagation from the SCS to the NW. The model results showed that SWH in the NW during peak phase of the TH (22nd - 23rd November 2007) varied between 0.8 – 3.5 m. There were 6 observation points in the study area to investigate SWH variation from 22nd October – 22nd December 2007. Based on the results, the northern part of the Natuna, Subi Besar and Anambas Islands are showed in Point 1 (P1), Point 3 (P3) and Point 5 (P5), respectively. Meanwhile, the southern part of the Natuna, Subi Besar, and Anambas Islands are showed in Point 2 (P2), Point 4 (P4) and Point 6 (P6). TH in the peak phase generates the SWH at P1, P3, and P5 of about 0.6 – 2.5 m and generates the SWH at P2, P4, and P6 of about 0.5 – 1.6 m.

1. Introduction
Natuna Waters (NW) is known as one of the strategic outer region of Indonesia, which is connected to the Indonesian Archipelagic Sea Lanes (ALKI I) [1]. The NW is Indonesia’s outer border area and directly facing to Malaysia, Singapore, Vietnam, and Cambodia. It also faces to a major international shipping route between East Asia and Indian Ocean [2]. As a border region, the NW is potential to be developed as a basis for national defense, tourism, and development of various other sectors. Another considered sector is wave energy utilization. Based on the results of existing studies, the waters in the vicinity of Natuna Islands are identified as potential areas for wave energy extraction [3]. An important result relates to this is showed by [4], they have analyzed climatic long-term trends of China Sea wave power and Significant Wave Height (SWH) for the period 1988 – 2011 using WAVEWATCH III (WW3) hind cast wave data. The result shows that the wave power density in December, January, and February (DJF) is stronger than in other seasons.

On the other hand, as the border of the country directly facing the SCS, NW has a vulnerability to extreme waves due to swell propagation. Wind-generated gravity waves are almost always present at sea. These waves are generated by winds somewhere on the ocean. They can be locally (seas) or thousands of kilometers away (swell) [5]. Wind sea and swell climate on a global scale have analyzed by [6]. The result shows that the global ocean is strongly dominated by swell waves. Moreover, studies related to wind waves in SCS have been carried out by [7]. Other than those already mentioned, wave data with high temporal and spatial resolution in the NW is a great significance for offshore and coastal engineering purpose [8], such as wave climate assessment [9-11], structure design [12-14], and vessel design [15-17].
In addition, from the best of our knowledge, there has been no numerical study which investigates wave characteristics in the NW, especially during typhoon event. In the current study, Simulating WAVE Nearshore (SWAN) model [18] has been applied for investigating wave characteristics in the NW during the TH event that has occurred between 20th – 27th November 2007 in the SCS. The outline of this paper is as follows. After introduction, a description of the model domain is described in section 2. Next, the form of data and methods are explained in section 3. Section 4 provides the model results. Whereas, in section 5, the conclusions are presented.

2. Model Domain
In this study, model domain consists of 2 domains namely Domain 1 (D1) and Domain 2 (D2). D1 and D2 are WW3 and SWAN model domains, respectively. The D1 covers Indonesian waters region and D2 encompasses western waters of Indonesia including NW, as shown in Figure 1. Detail information of the model domain is presented in Table 1.

![Figure 1](image1.png)

Figure 1. The nested grid system used for (a) D1 to (b) D2 (Blue box is NW domain)

![Figure 2](image2.png)

Figure 2. Bathymetry in the study area
Table 1. Detail information for the study area

| Domain Name | Coordinate | Spatial Resolution |
|-------------|------------|--------------------|
|             |            | Resolution (°)     | Resolution (km) |
| Domain 1 (D1) | 20° N – 20° S; 90° – 150° E | 1/8° | 13.875 × 13.875 |
| Domain 2 (D2) | 19° N – 13° S; 100° – 130° E | 1/24° | 4,625 × 4,625 |

3. Data and Methods

In this study, wind data obtained from Cross-Calibrated Multi-Platform (CCMP) and bathymetry data derived from the General Bathymetry Chart of the Ocean (GEBCO) are used as model input. CCMP and GEBCO data has spatial resolution of 0.25° × 0.25° (about 28 km) and 30 second (about 1 km), respectively. The bathymetry condition in the study area is shown in Figure 2. Meanwhile, open boundary values for the SWAN simulation are obtained from WW3 results, which are provided by the Indonesian Geospatial Information Agency (BIG).

SWAN is a third-generation discrete spectral wave model which describes the evolution of the wave energy spectrum in the two-dimensional mode under arbitrary wind and bathymetry conditions [19]. The SWAN model is used based on the equilibrium equation of action, which implicitly considers the interactions between waves and currents. In the SWAN model, the evolution of action density (N) is governed by action balance equation as follows [18]:

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S(\sigma, \theta, x, y, t)}{\sigma}$$  

(1)

where $c_x$ and $c_y$ are x and y components of group velocity corrected for propagation on a current with velocity, respectively. The quantities $c_\sigma$ and $c_\theta$ are the propagation velocities in spectral space ($\sigma, \theta$).

Meanwhile, the first term on the left-hand side in Equation 1 represents the local rate of change of action density in time, the second and third term represent propagation of action. The fourth term represents the shifting of the relative frequency due to variations in depths and currents. The fifth term represents the depth and current-induced refraction. The right-hand side in Equation 1 contains $S(\sigma, \theta, x, y, t)$, which is the source term that represents the effects of generation, dissipation and non-linear wave-wave interactions. The source term is given by using formula:

$$S = S_{sw} + S_{ds,w} + S_{nl4} + S_{ds,br} + S_{ds,b} + S_{nl3}$$  

(2)

These terms denote the deep-water source for a generation due to wind input, dissipation due to white-capping, non-linear quadruplet wave-wave interactions, and shallow water source term for dissipations due to depth-induced wave breaking, bottom friction, and triad wave-wave interactions [20].

In this research, the SWAN cycle III version 41.10 model [21] was used to perform hindcast study. Stationary mode simulation was run from 1st October – 31st December 2007 to cover the TH event with a time step of 15 minutes. The domain was discretized with a regular grid in spherical coordinates with a uniform resolution of 0.125° × 0.125° (about 14 km). Directional of wave propagation was discretized using 24 directional bins and frequency bins between 0.05 – 1 Hz. Numerical scheme was the BSBT (first-order upwind; Backward in Space, Backward in Time) scheme. Activated physical phenomena including the quadruplet wave-wave interactions and the dissipation term of wave energy is represented by the summation of three different contributions; depth-induced breaking, bottom friction, and white-capping. In this study, surface current variation is not activated.
4. Model Results
In this research, the simulated wave data were compared to observation data in Baron, Yogyakarta, referred to the research conducted by [22] (see their Figure 3). The results of the modelling are presented in two parts, namely spatial patterns of wind and waves during the TH event and time series of the SWH in several observation points.

4.1. Wind and wave characteristics during the TH event
Daily spatial patterns of the SWH and wind speed in the study area at the time of TH events (only 20\textsuperscript{th} – 24\textsuperscript{th} November 2007) are shown in Figures 3 to 7. The SWH patterns on 20\textsuperscript{th} November 2007 varies between 0.3 – 2.5 m with dominant direction to the southwest and the largest SWH is found in the northern part of the study area, whereas the wind speed varies between 5 – 13 m/s and the effect of the TH is already visible on wind patterns. On 20\textsuperscript{th} November 2007, position of the TH (low intensity) was in the west of the Philippine archipelago and moving towards the SCS. The SWH to the south of Natuna, Subi Besar, and Anambas Islands are smaller than the SWH to the north of those islands.

\textbf{Figure 3.} Spatial patterns of (a) wind speed, (b) SWH, and (c) TH position on 20\textsuperscript{th} November 2007 (Typhoon track source in Figure 3c was modified from http://agora.ex.nii.ac.jp).
Figure 4. Same as in Figure 3 but for 21st November 2007 (Typhoon track source in Figure 4c was modified from http://agora.ex.nii.ac.jp).

Figure 5. Same as in Figure 3 but for 22nd November 2007 (Typhoon track source in Figure 5c was modified from http://agora.ex.nii.ac.jp).
The SWH patterns on 21st November 2007 vary between 0.5 – 3.5 m with the dominant direction to the southwest. Meanwhile, the wind speed varies between 6 – 14 m/s with the dominant direction to the southeast. Currently, the position of the TH (moderate intensity) is in the west of Philippine archipelago and moving towards northwest of the SCS. Increase of typhoon intensity is followed by increase of SWH due to swell propagation.

**Figure 6.** Same as in Figure 3 but for 23rd November 2007 (Typhoon track source in Figure 6c was modified from http://agora.ex.nii.ac.jp)

Furthermore, on 22nd November 2007, the increase of intensity of the typhoon (high intensity) was caused by the increases of the wind speed. Therefore, the SWH has increased and the largest SWH (3.5 m) has begun to be distributed evenly. The SWH patterns at this time was varied between 0.8 m – 3.5 m with the dominant direction to the south. Meanwhile, the wind speed varied between 7 – 14 m/s with dominant direction from the northwest.

Meanwhile, due to the movement of the storm to the northwest away from the study area, the wind speed on 23rd November 2007 (high intensity) decreased to 2 - 10 m/s and the SWH varied between 0.8 – 3.5 m. However, the largest SWH (3.5 m) was not evenly distributed in the study area. As the storm moved away from the study area in NW, the wind speed on 24th November 2007 decreased to 1 – 6.5 m/s and position of the TH was in the SCS with moderate intensity. The SWH range in the study area was from 0.5 – 2.5 m.
Figure 7. Same as in Figure 3 but for 24th November 2007 (Typhoon track source in Figure 7c was modified from http://agora.ex.nii.ac.jp)

4.2. Time series of the SWH

In this analysis, 6 observation points have been chosen at the surrounding of the NW. The 6 observation points are shown in Figure 8. Point 1 (P1), Point 3 (P3) and Point 5 (P5) represent the northern part of the Natuna, Subi Besar, and Anambas Islands, respectively. Meanwhile, Point 2 (P2), Point 4 (P4) and Point 6 (P6) represent the southern part of the Natuna, Subi Besar, and Anambas Islands, respectively.

Figure 8. Observation point in the study area

Figure 9 shows observation points in the study area (P1, P3, and P5) and those points are closer and directly exposed to the source of the typhoon. Increases of SWH at P1, P3, and P5 up to 0.5-1 m were
captured due to the occurrence of TH on 22nd - 23rd November 2007 where before the TH event, SWH is ranging from 1 – 2 m at P1, P3, and P5.

Figure 9. Time series of SWH in (a) P1, (b) P3, and (c) P5

Figure 10. Same as in Figure 9 but for (a) P2, (b) P4, and (c) P6

Figure 10 displays the observation points at P2, P4, and P6. Those points are located at south of the Natuna, Subi Besar, and Anambas Islands, therefore those points are not directly exposed from swell
propagation. The highest SWH in those points is smaller compared to SWH at P1, P3, and P5, which is only 1.5 m. In general, TH do not strongly affect the SWH at P2, P4, and P6 as apprehended from a small SWH changes during the TH event.

5. Conclusion

The TH event changed wind pattern in the study area. The wind speed increased compared to normal conditions and the wind formed vortex with counterclockwise pattern. The TH caused a large velocity of wind to generate swell which made SWH in the study area especially at the observation points P1, P3 and P5 increase. The increasing SWH at P1, P3, and P5 reached 1 m and occurred on 22nd – 23rd November 2007 which was the peak phase of the TH (high intensity). While at P2, P4, and P6, the SWH changes were small because those points were protected by the Natuna, Subi Besar, and Anambas Islands and not directly exposed from swell propagation.

Geographically, the NW is identified as a place facing to the SCS. Therefore, the NW is affected directly by swell propagation from high latitude and increase SWH in the SCS and surrounding areas. The increased SWH can be exacerbated by typhoon. During typhoon event, SWH can be extreme and harmful, especially for shipping safety. Therefore, it is very important to consider ocean wave and the impact of the typhoon on the condition of NW for long-term sustainable development in the Natuna region.

Acknowledgment

Part of this study were funded by Bandung Institute of Technology (ITB) under Program Penelitian, Pengabdian kepada Masyarakat, dan Inovasi (P3MI) ITB 2019. The authors would also like to thank Dr. Ibnu Sofian, M.Eng (BIG) for providing WW3 model results, which are used for open boundary input in nested model (D2 domain).

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