Study of the influence of cempaka tropical cyclone on the height of sea waves in the South Java sea using the Delft 3D application

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Abstract. Tropical cyclone Cempaka entered South Java sea from 25th November 2017 until 27th November 2017 and caused strong winds and high waves. Delft 3D Modeling Simulation was used to investigate the effect of tropical cyclone Cempaka development on sea level rise in coastal areas and high waves in the South Java sea. The FNL wind data with a resolution of 0.25° x 0.25 ° and GEBCO bathymetry data with a grid resolution of 30 seconds was used as input to the Delft 3D model. The results of the study showed that there was an increase of significant wave height during the tropical cyclone Cempaka period with significant wave values from 1 to 3.5 meters on 27th November 2017. While for the value of sea level height in the coastal area showed results there was an increase during cyclone Cempaka period with anomalies values to 0.4. However, at the center of the cyclone had a low anomaly value that reached -0.2. From the results of the correlation test and RMSE test on sea level Delft 3D output obtained a correlation value of 0.85 and error 0.43 in the Sadeng, Yogyakarta. While the correlation test and RMSE test for the significant wave height parameter obtained a correlation value -0.198 and error value 0.168.

1. Introduction

Climate change has severe implications on planets and ecosystems [1,2]. Therefore, climate change is an international environmental issue and gets much interest from different stakeholders share. Climate change and global warming, in many ways, is already happening adverse impact on the environment and humanity [3, 4, 5].

The trend of extreme meteorological events has received great attention in recent years due to the many extreme events such as hurricanes or storms, droughts, and floods observed [6]. Changes in global climate and changes in the Earth’s hydrological cycle [7,8] have resulted in increased heavy rainfall and consequently increased surface runoff and flood risk [9]. One problem relates to extreme weather in Indonesia is tropical cyclones. It has been identified that there is an increasing trend of occurrence of tropical cyclones and typhoons in the western Pacific and Atlantic Oceans due to the global warming effects [10, 11].

A tropical cyclone is a form of extreme weather disturbance preceded by a tropical depression or an intensive center of low pressure above the ocean. It will trigger intensive convection and cloud formation processes. Generally, tropical cyclones occur in areas located between 10 ° and 20 ° from the equator with an occurrence frequency of 65%; for areas around 22 ° north latitude, tropical cyclones' occurrences are very low, around 13%. The Coriolis force influences the formation of a
tropical cyclone with a parameter value equal to 2 times the rate of rotation of the earth times the sinus of φ (latitude of the earth) [12].

Java Island is located between 113° 48'10" - 113° 48'26" East Longitude and 7° 50′10″ - 7° 56'41" South Latitude. The position of Java Island, which is bordered by the Indian Ocean in the south, causes the South Java Sea vulnerable to extreme weather events like tropical cyclones. From 42 years of historical data, it can be seen that in the South of Indonesia, the most frequent occurrence of tropical cyclones is in February, namely 23% of events in a month and followed by March (22%), January (21%), December (14%) and April (11%) [13]. High waves in the sea can be caused by a strong and long duration of wind blow. Tropical cyclones can cause an immediate impact on the surrounding area, which are the occurrences of high waves and the phenomenon of storm waves that can spread to coastal areas [14]. Therefore, some model to predict the sea water level is needed to prevent the risk caused by the tropical cycle, and Delft 3D application is one of the models that can be used.

Delft 3D application is used as a research tool in order to simulate waves by inputting wind, pressure, and bathymetry data as input models resulting in spatial analysis of the ocean waves as an output. Delft 3D uses the same equation in the SWAN model to calculate ocean waves in deep and shallow waters. Delft 3D can simulate waves on the coast that takes into account the value of bottom friction. It has been observed that the Delft 3D model is good enough at simulating high waves off the coast of Duck, North Carolina, caused by storms with an RMSE value of 0.14 [15].

Based on the description above, the Southern Java Sea waters were chosen as the research area because the seawaters of the South Java Sea are one of the areas directly affected by the Cempaka tropical cyclone. It is expected to provide information on the impact of the Cempaka tropical cyclone on the phenomenon of storm surge and high waves to assist weather forecasters at ports to issue early warnings of high waves due to tropical cyclones.

2. Research Methods

This research was conducted by descriptively analyzing the model's parameters and validating the model output data against the observational data. This research uses the Cempaka tropical cyclone event as a case study object. An assessment of the effect of the tropical cyclone on several marine parameters such as significant waves and sea level to determine the correlation and pattern compatibility of these parameters with the Cempaka tropical cyclone event. The output of the Delft 3D model is used as a reference model for the study in this research.

The research was conducted by descriptively analyzed the parameters that issued by the model with The location chosen in this study includes the South Java sea area and its surroundings, which are located between 7° latitude - 18° south latitude and 105° east longitude - 115° east longitude. The study's time limit coincided with the development period until the disappearance of the Cempaka tropical cyclone, from 23 November 2017 - 2 December 2017. The map of the research location can be seen in Figure 1.
Data from this research:
1. Cempaka tropical cyclone track data obtained from TCWC BMKG Jakarta.
2. National Centers for Environmental Prediction (NCEP) re-analysis wind model data with a spatial resolution of 0.25° x 0.25° from the period November 2017 as an additional parameter in the Delft 3D model, this data can be downloaded from the website [https://rda.ucar.edu/datasets/ds083.3/](https://rda.ucar.edu/datasets/ds083.3/).
3. The bathymetric data of the Southern Java Island water and its surroundings was obtained from the General Bathymetric Chart of the Ocean (GEBCO) with a spatial resolution of 0.30° x 0.30°.
4. Wind speed and direction data acquired from Panjang and Ciwandan AWS Maritime Stations to determine wind conditions the moment Cempaka Tropical Cyclone occurred.
5. Data from daily mean sea surface temperature NOAA OI SST V2 High-Resolution model with a spatial resolution of 1° x 1°.
6. Component data of astronomical tidal around the research area, downloaded from the site [http://oceanomatics.com/](http://oceanomatics.com/).
7. TML anomaly data obtained from the Jason-2 altimetry satellite with a spatial resolution of 0.25° x 0.25°, used for the analysis of sea level anomaly values during the Cempaka tropical cyclone, this data can be downloaded from the website [http://marine.copernicus.eu/](http://marine.copernicus.eu/).
8. Tidal observation data obtained from geospatial information agencies at several points on the southern coast of Java Island are used to validate data results, with the distribution of locations listed in table 1.

| No | Tidal Stations         | Coordinate       |
|----|------------------------|------------------|
| 1  | Sadeng Tidal Station   | 8.190 LS, 110.799 BT |
| 2  | Gelagah Tidal Station | 7.916 LS, 110.078 BT |
| 3  | Pacitan Tidal Station  | 8.226 LS, 111.076 BT |

Table 1. Names and locations of Tidal Stations

For Wave Data Processing:
1. Collecting data to be used in model simulations, which are the FNL model data prepared by NCEP and previously downloaded bathymetry data.
2. Converting FNL data from grid format to AMV, AMU, and AMP formats using the MATLAB application, the converted FNL data will be used in the Delft 3D application as additional wind and pressure parameters.
3. Creating the main domain and small domains grid for model nesting in the Delft 3D - RFGRID tool in the making of spherical coordinate grids, this will be used as grid coordinates, in order to equalize the grid coordinates with the coordinates in the FNL model.
4. Processing bathymetric data on the Delft 3D - QUICKIN menu, in this menu, the large domain grids that do not have a value (blank) will be filled with bathymetric data values using the triangular interpolation operation.
5. Using the Flow input menu to fill in some data input, which are the large grid domain, bathymetry, wind (direction and speed), pressure, and research domain boundaries.
Figure 2. Delft 3D flow input toolbar view

6. On the Flow menu, select the domain toolbar to input bathymetry data, research large domain grid, and grid enclosure, and then other inputs which are selected by default.

7. Use the Time Frame toolbar to describe the initial running time of the model and the time step model, in this study the initial time was carried out on 20 November 2017 at 00 UTC to 3 December 2017 at 00 UTC with a time step of 10 minutes.

8. Select the Process toolbar to determine the parameters used in wave prediction, to coupling the flow model with the wave model, click check on the wave parameter.

9. Creating boundaries conditions on the Boundaries toolbar, in this research astronomic boundary conditions were used.

10. Select the Physical Parameters toolbar and click check on the varying wind and pressure in the wind toolbox.

11. Select the Monitoring toolbar to enter the location of the tidal observation station in the grid that has been created.

12. Select the Additional Parameters toolbar and then fill the table with the converted FNL files, the converted FNL data must be located in work folder.

13. Select the Output toolbar then input an identical running time and time step running model with the input time frame, after the input flow is complete, the input flow is saved in the form of .mdf file.

14. Click the wave input and select the domain menu to input grid and model simulation enclosure.

15. Click check on Run WAVE together with FLOW on the hydrodynamics toolbox to perform coupling between the flow model and the wave model. When the wave model is coupled with the flow model, the wave input description will automatically be the same as the input flow and then will be stored in the form of .mdw file.

16. Run the Flow and Wave model on the start sub-menu in the flow menu.

Model Verification:
In this study, the output of the Delft 3D model was verified using real-time sea level observation data from BIG (Geospatial Information Institute) using the statistical calculation method RMSE (Root Mean Square Error) and the relation coefficient used to find the relationship between different variables. When the correlation gets closer to zero, the model output is getting closer to the true value. The formula used in the calculation of RMSE is as follows [16].

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (e_i - \bar{e_i})^2}
\]
Description:
\[ n = \text{the amount of data} \]
\[ e = \text{variable values of the output model} \]
\[ \varepsilon = \text{variable values from real-time observation} \]

in order to show the similarity between the output model and observational observations, the following equation is used [17].

\[
r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n\Sigma x^2 - (\Sigma x)^2} \cdot \sqrt{n\Sigma y^2 - (\Sigma y)^2}}
\]

Description:
\[ r = \text{relation coefficient} \]
\[ n = \text{the amount of data} \]
\[ x = \text{real-time observation variables} \]
\[ y = \text{the output model variables} \]

3. Results and Discussions

The study material in this research is meteorological parameters and marine parameters, which are used to analyze the effect of the Cempaka tropical cyclone on storm waves and sea wave heights in the South Java Sea. Wind data from the FNL model is used as wind data input for the 3D running delft model with a spatial resolution of 1° x 1°. For the analysis of the Cempaka tropical cyclone's development pattern in the southern part of the Java Sea, the streamline 925 mb ECMWF layer model was used with a spatial resolution of 0.25° x 0.25°. It was indeed a fact that tropical cyclones cause sea level rise on the coast. Therefore altimetry satellite data is used to monitor sea level anomalies on the southern coast of Java. The simulation results from Delft 3D of the sea wave model and the sea level were used to see the effect of the Cempaka tropical cyclone on high waves in the southern Java sea due to the lack of observational data. The research was conducted in the South Java Sea with a spatial domain located between 7° S - 18° S and 105° East - 115° E from 23 November 2017 - 2 December 2017.

Cempaka cyclone seeds’ initial growth occurred at a low-value pressure center of 1003 mb at the coordinates of 9.6° S and 109.40° East with a maximum wind speed of 25 knots. The center of low pressure of tropical cyclones generally moves eastward with the last sequence of cyclone centers being at coordinates 9.9° S and 110° East. The highest wind speed value in the Cempaka tropical cyclone is 35 Knots which occurred on 27 November 2017 to 28 November 2017 with a tropical cyclone center pressure value of 999 mb - 998 mb

3.1 ECMWF Streamline Model Analysis

The streamline condition before the occurrence of a tropical cyclone is represented in Figure 4. Taken from the 925 mb layer of the ECMWF wind output model from 23 November 2017 to 24 November 2017. When the tropical cyclone has not yet been developed, there is a cyclonic patterns movement, moving from the eastern Java region to the southern region of Java Island waters. At that time, the growth of tropical depression was identified in the southern waters of Java Island with wind speed around 5 to 15 knots.

3.2 Analysis of Sea Surface Anomaly Satellite Data

Sea level anomalous conditions during the Cempaka tropical cyclone period 23 November 2017 - 2 December 2017 are presented in Figure 4 using Jason-2 satellite data. In the period before the Cempaka cyclone, areas near the coastline of South Java had anomalous sea level values ranging from 0.2 to 0.3, indicating that the sea level value was higher than usual. For the middle region in the cyclone pattern, the sea level anomaly ranges from -0.2 - -0.1; this indicates that the sea level is lower than normal. The negative anomaly value at the center of the cyclone pattern is possible due to the presence of Ekman currents from the cyclone vortex, which causes sea level divergence, which pushes the seawater mass away from the center of the cyclone, and a decrease in sea level occurs. During the Cempaka tropical cyclone development period, the sea level anomaly in the area near the coastline
tends to increase positively. Sea level anomalies near the coastline of South Java have an anomaly ranging from 0.2 to 0.4. From this data, it can be seen that generally, tropical cyclones can affect sea level rise in areas close to the coastline. For the period after the Cempaka tropical cyclone, sea level rise can occur due to the full moon’s influence in the early December period, which causes the tide.

![Figure 3](image1.png)

**Figure 3.** The Streamline of layer 925 at the time before, during, and after the Cempaka cyclone at the 925 mb layer

![Figure 4](image2.png)

**Figure 4.** Sea level anomalies before and during the Cempaka tropical cyclone

### 3.3 Analysis of Sea Surface Anomaly Satellite Data

Delft 3D sea level output analysis is carried out in several stages, from collecting model output to model verification. Each model runs using the same bathymetric and wind input data. This analysis was carried out to see the ability of Delft 3D in simulating sea level height parameters as input wave models.

#### 3.3.1 Verification of 3D Delft Flow Models

Data with a period of 6 days were used to find the correlation value and RMSE from November 2, 2017, to November 7, 2017. From these results, the simulation in the Sadeng area is the best simulation with a correlation value of 0.85 while the RMSE
value has an error of 0.54. Cilacap area has the lowest correlation value and the biggest error with a correlation value of 0.52 and an error of 7.54. In general, the Delft 3D model is good enough to simulate the parameter values of sea level in coastal areas and tidal patterns, but for the Cilacap area the simulation results are not good, this is possible due to poor grid construction according to the topography.

Table 2. Correlation value and RMSE output of 3D Delft Flow model

| Num. | Tidal Stations | Correlation | RMSE  |
|------|----------------|-------------|-------|
| 1    | Cilacap        | 0.52        | 7.54  |
| 2    | Sadeng         | 0.85        | 0.43  |
| 3    | Pacitan        | 0.82        | 0.54  |

3.3.2 Verification of 3D Delft Flow Models

Figure 5 Comparison graph of the Delft 3D model's sea level parameter output with observations in the Sadeng area

Figure 6 Comparison graph of the Delft 3D model's sea level parameter output with observations in the Pacitan area
Figure 7 Comparison graph of the Delft 3D model's sea level parameter output with observations in the Cilacap area

It can be seen that the output values of the Delft 3D model sea level parameters generally have the same tidal pattern as the observed sea level values in the Cilacap area, but the values with the Delft 3D model output are too underestimating compared to observations. The highest tide value occurred on November 6, 2017 at 15.00 UTC with an observed value of 9.53 m, while the Delft 3D simulation results had a value of 1.54 m. The lowest ebb value occurred on November 6, 2017 at 21.00 with an observation value of 7.46 m, while the Delft 3D simulation results had a value of -0.145 m. In general, Delft 3D models are good enough in simulating tidal patterns in the Cilacap area, but the simulation results tend to be underestimated due to poor grid construction.

3.4 Analysis of Significant Wave Height Delft 3D Output

3.4.1 Wave Model Verification. In the correlation test between the Wave Delft 3D model with observations, it shows to have a value of -0.198; the model has an inverse relationship with the observed value, and the correlation value that does not approach the value of 1 or -1 indicates a low correlation between the model and the observation. The RMSE test between the model and observation has a value of 0.168, which is close to 0, which means that the model has a small error value for the observation. The Delft 3D model can simulate significant wave height parameters with small errors but with low correlation from this test.

| Num. | Test      | Value  |
|------|-----------|--------|
| 1    | Correlation | -0.198 |
| 2    | MAE       | -0.03  |
| 3    | MSE       | 0.028  |
| 4    | RMSE      | 0.168  |

3.4.2 Significant Wave Height Analysis. The simulation results of significant waves of the Delft 3D model during the period when the Cempaka cyclone occurred is represented in Figure 8. The simulation was performed using the default Delft 3D model scheme. Before the Cempaka tropical cyclone, the general significant wave conditions near the southern coastline of Java were relatively high, with values ranging from 1 - 3.5 m.

On 25 November 2017 at 00.00 UTC, generally, the significant wave height in the southern waters of Java Island ranges from 0.25 to 3.5 m and is higher than the previous condition. The maximum high waves occurred on 27 November 2017 at 12.00 UTC, with the wave height value in the area near the coast reaching 3.5 m categorized as rough sea category. After 27 November, the wave height generally decreases to 0.2 - 2 m. During the Cempaka tropical cyclone, the Southern waters generally
have significantly higher waves than the previous condition; this shows that high waves can be formed when the cyclone occurs.

![Figure 8](image.png)

**Figure 8** The output of the significant wave height parameter of the Delft 3D model during the Cempaka cyclone

The simulation results of significant waves of the Delft 3D model during the period when the Cempaka cyclone occurred is represented in Figure 8. The simulation was created using the default Delft 3D model scheme. Prior to the Cempaka tropical cyclone occurrence, the general conditions of a significant wave near the southern coastline of Java were quite high, with values ranging from 1 to 2 m.

4. Conclusion

The conclusion is in general, the Cempaka tropical cyclone lowers sea level at the center of the cyclone with anomalous value of sea level reaching -0.2, whereas, for coastal areas the Cempaka tropical cyclone causes a rise in sea level, but from the data it can be seen that after the Cempaka cyclone is over the rises in sea level is due to full moon and Dahlia tropical cyclones with sea level anomaly values reaching 0.4, based on the research analysis, it can be seen that a significant increase in wave height is directly proportional to the growth of tropical cyclones with the significant wave height parameter value of the model output reaching 3.5 meters near the center of the Cempaka tropical cyclone, Delft 3D model is good enough to simulate sea level parameters with the highest correlation value and lowest error in the simulation of Pacitan area with a correlation value of 0.82 and RMSE 0.54, while for the simulation of significant wave height parameters it has a low error value 0.168 in RMSE but for the significant wave height parameter, it has a poor correlation with a value of -0.198.

References

[1] Crabbe M J C 2009 Modelling effects of geoengineering options in response to climate change and global warming: implication for coral reefs *Computation biology and chemistry* **33** 415-420.

[2] Rahmat A and Mutolib A 2016 Comparison of air temperature under global climate change issue in Gifu city and Ogaki city, Japan *Indonesian Journal of Science & Technology* **1** (1) 37-46.

[3] Ahmad N NN and Hossain D M 2015 Climate change and global warming discourses and disclosures in the corporate annual reports: A study on the Malaysian companies *Procedia-social and behavioral sciences* **172** 246-253.
[4] Rahmat A, Zaki M K, Effendi I, Mutolib A, Yanfika H, Listiana I 2019 Effect of global climate change on air temperature and precipitation in six cities in Gifu Prefecture, Japan Journal of Physics: Conference Series 1155 012070

[5] Martin Y, Permpa D, Ulya A, Despa D, Marwansyah, Rahmat A 2020 Ufer Grounding System to Minimize Risk of Lightning Strike using Concrete Mixed with Bentonite and Coconut Fiber Jurnal Ilmiah Pendidikan Fisika Al-BiRuNi 9 133-140

[6] Easterling D R, Evans J L, Groisman P Y, Karl TR., Kunkel K E and Ambenje P 2000 Observed variability and trends in extreme climate events: a brief review Bulletin of the American Meteorological Society 81 417–425.

[7] Allen M R and Ingram W J 2002 Constraints on future changes in climate and the hydrologic cycle Nature 419 224–232.

[8] Wentz F J, Ricciardulli L, Hilburn K and Mears C 2007 How much more rain will global warming bring? Science 317 233–235.

[9] Trenberth K E 2011 Changes in precipitation with climate change Clim. Res. 47 123–138.

[10] Emanuel, K. A. 2005. Increasing destructiveness of tropical cyclones over the past 30 years Nature 436 686-688.

[11] Webster P J, Holland G J, Curry J A and Chang H R 2005 Changes in tropical cyclone number, duration and intensity in a warm environment Science 309 1844-1846.

[12] Syaifullah M D 2016 Siklon Tropis, karakteristik dan pengaruh wilayah Indonesia pada tahun 2012 Jurnal Sains dan Teknologi Modifikasi Cuaca 16 61-71

[13] Azis M F 2006 Gerak Air Dilaut, Lembaga Ilmu Pengetahuan Indonesia.

[14] Booij N, Ris R, and Holthuijsen L 1999 A third-generation wave model for coastal regions, Journal of Geophysical Research 104 7649–7666.

[15] Dafitra I 2018 Analisis Pasang Surut, Gelombang dan Swell Saat Kejadian Banjir Pesisir Padang, Program Sarjana Sains Terapan, Sekolah Tinggi Meteorologi Klimatologi dan Geofisika, Jakarta.

[16] Deltares 2007a User Manual Delft3D-RGGRID: Generation and Manipulation of curvilinear grids for FLOW and Wave, Deltares, Delft, Belanda.

[17] Deltares 2007b User Manual Delft3D-WAVE: Simulation of short-crested waves with Swan, Deltas, Delft, Belanda