Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram
https://e-journal.undikma.ac.id/index.php/prismasains/index
e-mail: prismasains.pkpsm@gmail.com

April 2023. Vol. 11, No. 2
p-ISSN: 2338-4530
e-ISSN: 2540-7899
_pp. 450-462_

Analysis of Interaction Between Atmosphere and Sea Using The Delft3D Hydrodynamics Model for Mapping Coastal Flood Zone at Belawan Port and Coastal

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Received: March 2022; Revised: March 2023; Published: April 2023

Abstract

Belawan port and coastal areas were also not spared from the impact of the tidal flood. This study aims to determine the performance of the Delft3D hydrodynamic model in simulating sea level and waves in tidal floods at Belawan port and coastal area. Final operational global analysis data, MSLP data from NOAA/NCEP, and tidal data from ECMWF were used to run the Delft3D model. The model output was verified by using tide gauge observation data from BIG (Geospatial Information Agency). This research resulted in a mapping of areas affected by tidal flooding in the Belawan port and coastal area by analyzing the interaction between atmosphere, consisting of wind speed and direction parameters and sea parameters in the form of significant wave height. Based on the results of the Delft3D verification with observation data, the average error value is 23.5 cm and the coefficient of correlation is 0.93. This shows that the Delft3D model is quite good at simulating tidal flood heights in the Belawan port and coastal area. Based on atmospheric analysis, it does not really affect the increasing wave height. The influence is given by significant sea wave height, which can increase the height of tidal floods.

Keywords: Atmosphere, Delft3D, Tidal Flood, Sea, Verification

How to Cite: Putra, R., Nasution, T., Humaidi, S., & Darmawan, Y. (2023). Analysis of Interaction Between Atmosphere and Sea Using The Delft3D Hydrodynamics Model for Mapping Coastal Flood Zone at Belawan Port and Coastal. *Prisma Sains : Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram, 11*(2), 450-462. doi:https://doi.org/10.33394/j-ps.v11i2.7773

https://doi.org/10.33394/j-ps.v11i2.7773

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INTRODUCTION

Indonesia is a country that is nicknamed the maritime continent, where the sea area is more dominant than the land area. This is a big advantage for Indonesia both in terms of social, economic and transportation. Indonesia is also an archipelagic country which has a coastline of 95,181 km. Long coastlines and vast oceans also cause Indonesia to face environmental problems and vulnerabilities (Marfai & King, 2008). Marfai and King (2008) explained that the environmental vulnerability for coastal areas that has the most impact is sea level rise which results in coastal erosion, tidal flooding, and land change, as well as increased salinity in estuaries and aquifers.

The Belawan port and coastal areas are special areas that has national and international scale ports for both mass and goods transportation. Belawan Port has a fairly high number of annual container loading and unloading with domestic container loading and unloading of

98,000 tons, domestic container loading of 8,024,000 tons, foreign container loading of 5,696,000 tons, and foreign container loading and unloading. domestically 2,027,000 tonnes, as well as the number of domestic and foreign ship visits 3,896 with 37,200 GT so that tidal flood information is urgently needed to support the safety and smooth running of economic, social and transportation activities in the area. Belawan port and coastal areas were also not spared from the impact of the tidal flood. Tidal floods have become natural disasters that have caused various losses in affected areas and are often associated with clear evidence of the current effects of sea level rise. Factors that influence the occurrence of tidal floods are sea level rise in the long term, land subsidence, tides, and dynamic meteorological factors (Habibie et al., 2012).

Parameters that can trigger tidal flooding in coastal areas include waves, sea level rise and weather conditions. Sea waves can cause flooding in low coastal areas, where the water level is a combination of mean sea level or MSL (Mean Sea Level), tides, and waves (Wolf, 2008). Maulana and Hartanto (2010) state that in coastal vulnerability studies, significant wave height is a parameter related to coastal inundation hazard. Furthermore, tidal floods accompanied by storms, distant overflows, tidal floods accompanied by storms, river overflows, and high waves can have a serious damaging impact on coastal areas (NOAA, 2019). Waves combined with higher water levels can damage levees, cause flooding, destroy construction and erode beaches.

Research on the impact of tidal flooding using the Delft3D hydrodynamic model has been carried out by Kuntinah et al. (2021). This study aims to determine the performance of the Delft3D hydrodynamic model in simulating sea level height and waves during tidal floods. Final Operational Global Analysis (U,V) and MSLP data from NOAA/NCEP (National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction) and tidal component data from Oceanomatics were used to run the Delft3D model.

The model output in the form of sea level height is verified using tide gauge observation data from BIG which is then used in analyzing sea level height. Accumulated rainfall data from GSMaP data, wind and pressure from ECMWF, as well as observational pressure, wind and rainfall data were also analyzed to describe the hydrometeorological conditions during the flood event. Based on the simulation of sea level height during tidal floods, it is known that the Delft3D hydrodynamic model shows quite good performance. Even though the pure sea level height from the simulation results has a fairly high error, the model is able to reproduce the pattern of rise and fall of sea level very well. Research on sea level rise that causes coastal flooding has been carried out by Rasyda et al. (2015) research was conducted in the coastal area of the city of Padang, West Sumatra. This study aims to determine the trend of sea level rise in the city of Padang, which is generated by sea level rise. This study uses a spatial approach through DEM processing derived from high points on the RBI map of the city of Padang at a scale of 1:10000 and field observations, as well as tidal data from the Geospatial Information Agency (BIG) which are then processed to obtain an average MSL (MeanSea Level) value monthly and yearly.

Research on coastal flooding due to sea parameters has been carried out by Dafitra et al. (2020). This study aims to determine the relationship between significant waves (Hs) and swells to tidal flooding in the coastal area of Padang city. The data used are tidal data from the Geospatial Information Agency (BIG), significant wave data (Hs) and swell which are the result of processing from the Wavewatch-III model. Then sea level height data from the JASON-2 altimetry satellite. The results of this study indicate that there is a link between the occurrence of tidal floods and the high significant waves (Hs) and swells that occur.

The Meteorology, Climatology and Geophysics Agency (BMKG) through the Belawan Maritime Class II Meteorological Station informed that the tidal flood phenomenon hit the Belawan coastal area including Medan Belawan sub-district, as well as parts of Medan Labuhan sub-district and Medan Marelan sub-district. The phenomenon of tidal floods every year is increasingly concerning and troubling, because the height of tidal floods is getting higher every year and can occur twice a day during the highest tide period. The impact of tidal floods greatly disrupts people's lives, social and economic activities so that serious and measurable mitigation must be carried out immediately, one way is to map the areas affected by tidal floods in the Belawan port and coastal area.

Based on the description above, researchers want to map the areas affected by tidal flooding in the coastal area of Belawan by analyzing the interaction between the atmosphere consisting of wind direction and wind speed parameters and sea parameters in the form of significant wave heights using the Delft3D hydrodynamic model. The Delft3D hydrodynamic model has advantages in mapping tidal floods because it has high resolution, is easy to operate, the availability of free and easily accessible input data, fast data processing and can be linked to other phenomena so that the resulting model output is more accurate. The results of the mapping of sea water levels due to tidal floods are then verified by data verification by comparing the output data of the Delft3D model with data from sea tide observations from the Geospatial Information Agency (BIG). It is hoped that by mapping the potential impact of tidal floods it can provide fast, precise and accurate early warning information and help mitigate disasters caused by tidal floods in the Belawan port and coastal area.

Delft3D Hidrodynemical Model

Delft3D was developed by Deltares, an independent institute owned by Delft University of Technology for research in water, underground and infrastructure with a focus on deltas, coastal areas and watersheds. The strength of Delft3D is the availability of open source software for educational and research purposes. The Delft3D model used in this study is Delft3D version 4.04.02 with an official license that is valid forever. Delft3D can be installed on computers with Windows and Linux operating systems. The Delft3D hydrodynamic model shows quite good performance. Even though the pure sea level elevation values from the simulation results have a fairly high error, the model is able to reproduce the pattern of rise and fall of sea level very well (Kuntinah et al, 2021). Delft3D has several operating modules, including:

- Delft3D – FLOW, used to model hydrodynamic phenomena, especially currents due to tides and other meteorological forces.
- Delft3D – WAVE, used to model the transformation due to wave propagation from the deep sea to the coast.
- RFRGRID, creates a mesh/grid/lattice that will be made into a computational grid, namely the points where numerical calculations are calculated.
- QUICKIN, prepares grid data, in the form of bathymetry data, initial conditions for water level, salinity or concentration of other components.
- GPP, displays simulation results in the form of animated images and visualizations.
- Delft3D – QUICKPLOT, displays simulation results in the form of animated images and visualizations.

Delft3D in its calculations uses the Navier Stokes equation. The Navier Stokes equation is a non-linear differential equation that describes how a fluid flows. The pattern of Navier Stokes is:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial u}{\partial z} = 0 \quad \text{(Eq. 1)}$$

Incompressible Navier-Stokes equation on the x component:

$$\rho \left(\frac{\partial u}{\partial t} + U\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial P}{\partial x} + \rho g x + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \quad \text{(Eq. 2)}$$

Incompressible Navier-Stokes equation on the y component:

$$\rho\left(\frac{\partial v}{\partial t}+U\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial x}+\rho g x+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad \text{(Eq. 3)}$$

Incompressible Navier-Stokes equation on the z component:

$$\rho\left(\frac{\partial w}{\partial t}+U\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial x}+\rho g x+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad \text{(Eq. 4)}$$

Figure 1. Delft3D Hidrodynamical Model

Tidal Flood

Tidal floods are floods that are generated from high tides and cause damage to buildings, infrastructure, and hinder community and industrial activities (BMKG, 2010). Tidal floods can be caused by sea water that inundates the land. This seawater flood can occur if a land has a lower altitude than sea level.

The phenomenon of tidal flooding or tidal flooding generally occurs in urban areas located on the coast, such as Belawan, Semarang, and northern Jakarta. Tidal floods occur almost every year, even now they occur every month, both during the rainy and dry seasons. Rainfall is not a determining factor in causing tidal floods (Rangga & Rima, 2013). The increase in sea level due to global warming can also trigger tidal floods.

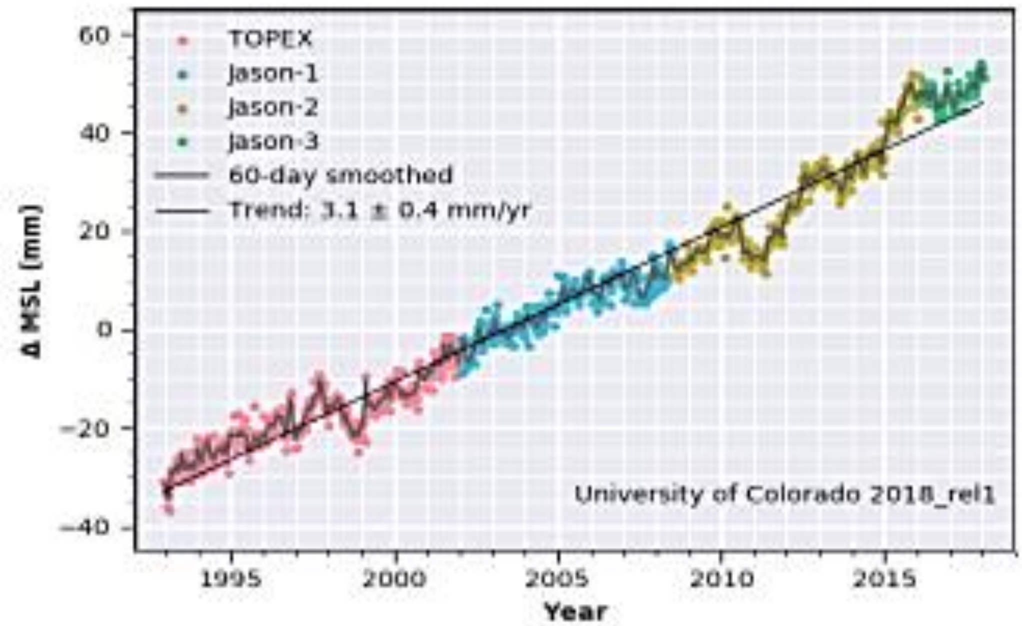

Figure 2. Sea Level Rise Year by Year
Source : http://sealevel.colorado.edu/

Sea Wave

Sea wave is the movement of rising and falling sea level in a perpendicular direction where the sea level forms a sinusoidal curve/graph which is generally caused by wind. Sea waves are a form of energy transmission that is usually caused by wind blowing over the surface of the sea water and hoarding the mass of sea water to form mountains of water which we know as waves. The stronger the wind blows, the bigger and taller the waves are formed, the wider the area affected by the wind (fetch), the bigger and taller the waves are formed. The longer the wind blows in an area, the bigger and higher the waves are formed, and the deeper the ocean where the waves are formed, the bigger the waves are created.

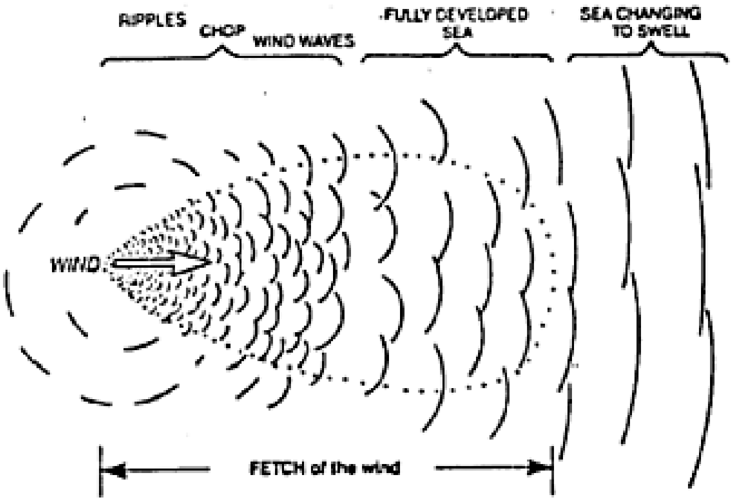

Figure 3. Variation of wave type and size along the fetch
Source: www.noaa.gov

Wind

Wind is a phenomenon of air movement triggered by differences in air pressure as a result of differences in temperature on the earth's surface, expressed in direction and speed. The greater the pressure difference that occurs, the greater the wind generated.

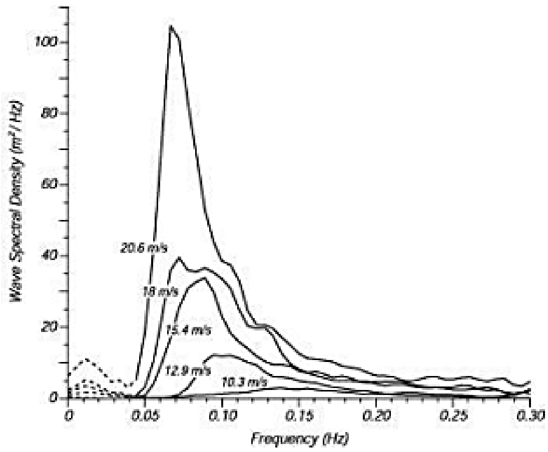

Figure 4. Wave spectrum for different wind speeds
(Pierson dan Moskowitz, 1964)

METHOD

Research Design

The type of research used in this study is descriptive quantitative research. Quantitative descriptive research was carried out by spatially and temporally describing the results of the Delft3D modeling in mapping the tidal flood heights combined with an analysis of interactions with the atmosphere and sea. Quantitative data is data in the form of numbers/can be calculated with varying values, where in this study the quantitative data processed were tidal flood height data, wind direction, wind speed, significant sea wave height, and sea tide data as a result of observations with.

Research Location

The research location is focused on around the coastal areas and waters of Belawan where the area is an area affected by tidal floods. The domain creation process in the Delft3D hydrodynamic model is adjusted to astronomical coordinates 3^0N - 4^0N dan 98^0E - 99^0E.

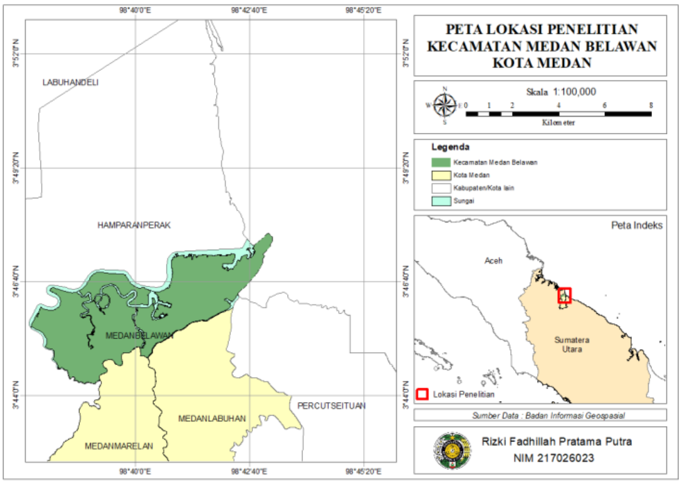

Figure 5. Research Location

Data

This research use 3 months data, from Januari to March 2022. The data used in this study are:

1. Delft3D input data : Final analysis data (FNL), Bathymetry Data, MSLP from NOAA, and ECMWF data.
2. Wind data final analysis with resolution 0.125^0 x 0.125^0
3. Sea Significant wave final analysis data with resolution 0.125^0 x 0.125^0
4. Tidal observation data from Geospatial Information Agency (BIG)

Data Collection

1. The Data Master Definition Flow file (MDF-file) which contains all the parameters that are the initial generators and numerical methods can be accessed through the official deltares website at http://deltares.nl.
2. Atmospheric variable data in the form of wind direction and speed in the form of final analysis data (FNL) can be downloaded from the official website of the National Centers For Environmental Prediction, http://rda.ucar.edu.
3. Wind direction and speed data are data from the Wavewatch-III wave modeling which can be downloaded on the map-maritim.bmkg.go.id/render website.
4. Significant sea wave height data is the result of Wavewatch-III wave modeling which can be downloaded from the map-maritim.bmkg.go.id/render website.
5. Verification data in the form of sea tide measurement data can be accessed via the Geospatial Information Agency (BIG) website at srgi.big.go.id.

Verification Metode

Error

The calculation of the bias is carried out on the tidal flood height values resulting from the output of the Delft3D hydrodynamic model with values obtained from tide observations from the Geospatial Information Agency (BIG). The calculation is done by reducing the value of the model with the observed value and then averaging the values.

$$ME = \sum_{i=1}^{n} \frac{(Xi-Yi)}{N} \qquad \text{(Eq. 5)}$$

With Xi is Model data, Yi is Observation data, n is lots of data.

Coeffisient Correlation

The value of the coefficient correlation is used to indicate the level of similarity of the linear pattern in the output data of the Delft3D hydrodynamic model with the BIG tide observation data. The correlation coefficient is denoted by the symbol 'r' with a value range of -1 to 1 ($-1 < r < 1$). If the value of r = 1 means that the positive linear relationship between the variables being compared is very strong, the value of r = (-1) means that the negative linear relationship between the variables being compared is very strong, and the value of r = 0 means the relationship between the variables being compared is not linear. The following is the equation for calculating the correlation coefficient value.

$$r = \frac{\sum_{i=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x-\bar{x})^2 \sum_{i=1}^{n}(y-\bar{y})^2}} \quad \text{(Eq. 6)}$$

With r is coeffisient correlation, n is lots of data, x is value for variable x, $\bar{x}$ is variable value average x, y is value for variable y, and $\bar{y}$ is variable value average y.

RESULTS AND DISCUSSION

Data Processing

Data Processing Creating research domains, inputting bathymetry, weather data, and boundary layers. At this stage it will produce output files with the extension grd, enc for domain, bnd extension, bca for boundary, dep extension for bathymetry, and amp, amu, amv extensions.

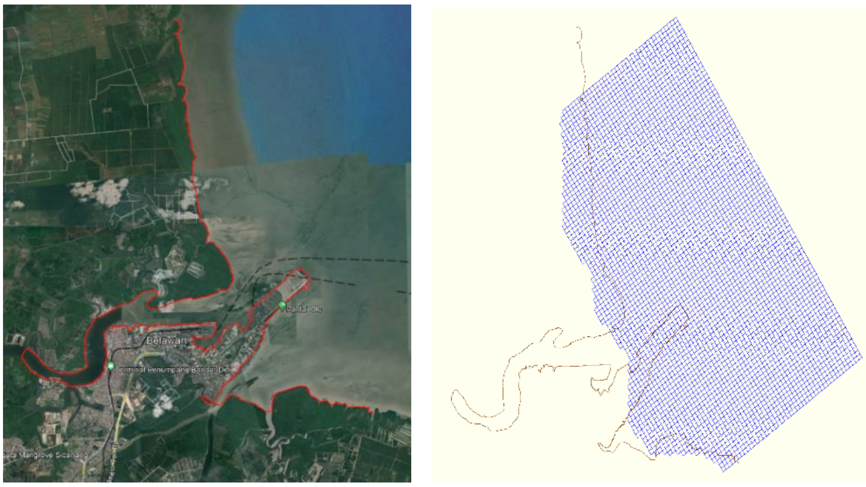

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Figure 6. Research Domain

The next process is bathymetry data processing. The bathymetry data will be more accurate the closer the values are, the better the resulting model will be. Domain and bathymetry must be considered in as much detail as possible, especially the areas bordering the coastal areas.

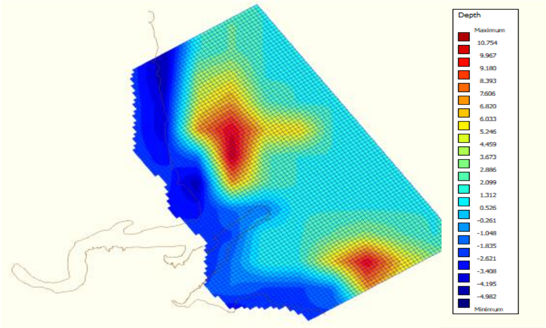


Figure 7. Bathymetry Domain

The next stage is processing. The processing stages are carried out depending on the advanced method you want to do. In the processing will do the stages of nesting and coupling. The nesting stage requires two domains, namely the large domain and the small domain. Furthermore, it requires several parameters (*.grd, *.enc, *.dep) for the processing stage.

The last stage is post processing. This stage will visualize the trim and wavm file results. Visualization can be done in two ways, namely Quickplot and Matlab. Quickplot has a weakness when the coast is directly adjacent to the cliff.

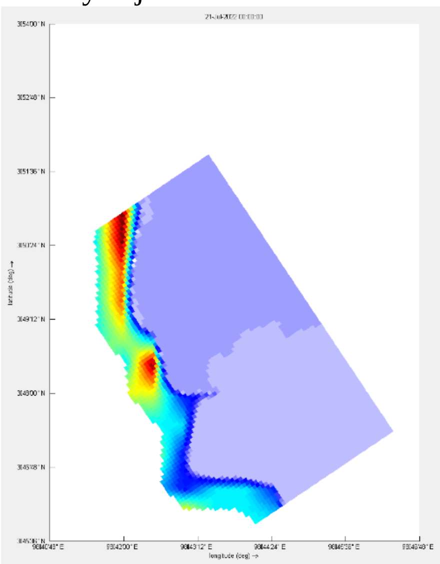


Figure 8. Nesting Spatial Water Level

Wind analysis uses Final Analysis Data (FNL) which is run on the WAVEWATCH-III wave model. The following is the result of mapping the average wind conditions in the research months from January to March 2022.

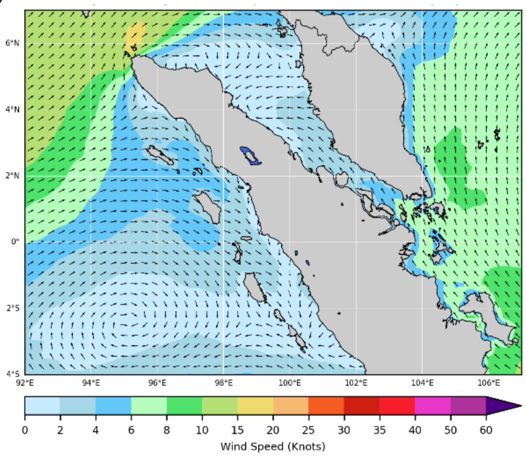


Figure 9. Wind Speed and Direction

Analysis of significant sea waves using Final analysis (FNL) data which is run on the WAVEWATCH-III wave model. Following are the results of mapping the average significant wave wind conditions in the research month January to March 2022.

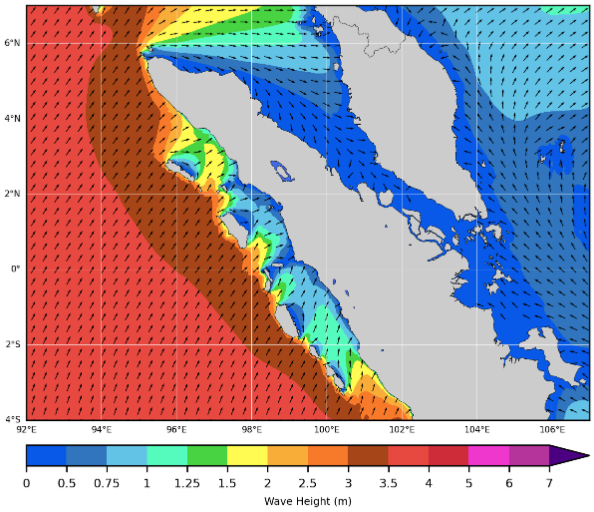
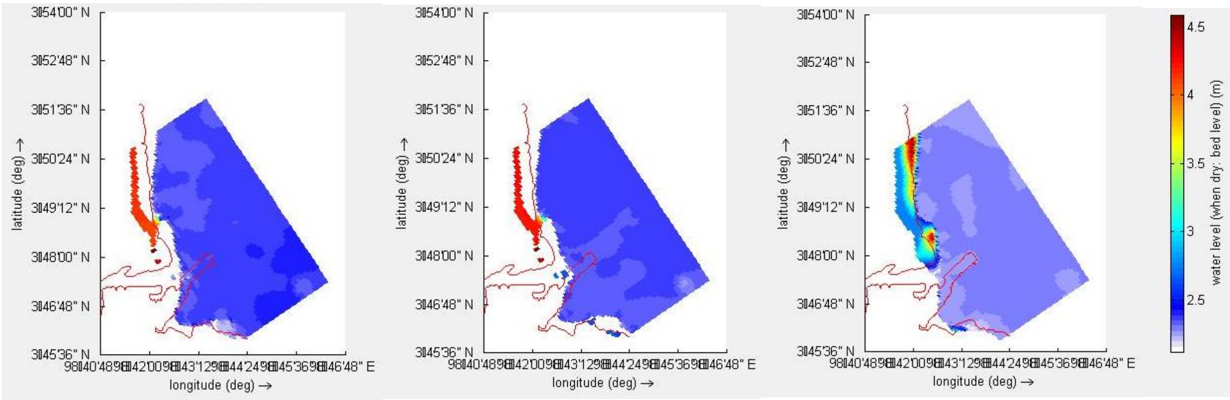


Figure 10. Significant Wave Height

Delft3D Data Analysis
Spatial Analisys



(a) **(b)** **(c)**

Figure 11. Delft3D Analisys (a) Januari, (b) Februari, (c) Maret

Tidal data output from the Delft3D hydrodynamic model in January 2022 shows that the peak tide in the Belawan coastal area occurred from 01 to 06 with the highest tide height of 2.25 m (225 cm), in February 2022 shows that the peak tide in the Belawan coastal area occurred from 01 to 06 with the highest tide height of 2.15 m (215 cm) and in March 2022 shows the peak tide in the Belawan coastal area occurs on the 17 to the 23 with the highest tide height of 2.55 m (255 cm).

Temporal Analisys

Delft3D data can be presented in a time series hour by hour. This is done to see the pattern of tides that occur. the tide pattern can determine the type of tide that occurs, in this result it is known that the type of tide in the Belawan port and coastal area are mixed tide prevailing semi-diurnal). Delft3D is able to display hourly data so that it can be known when the peak tide occurs. This data can also be used to find out when the lowest tide occurs. The following is a table of tide events processed by Delft3D.

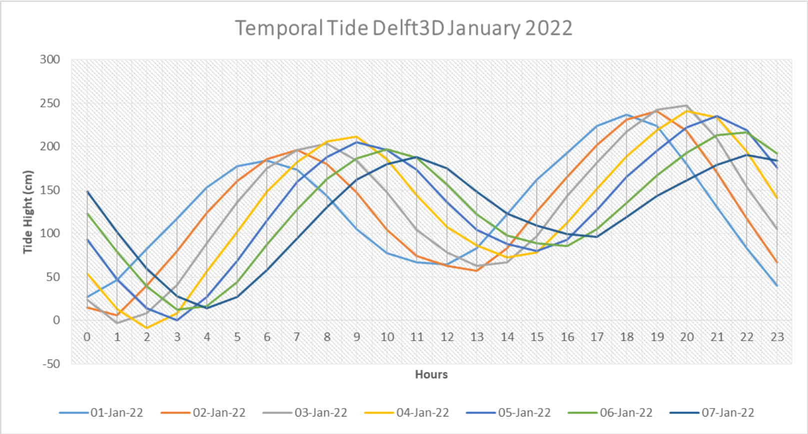


Figure 12. Temporal Tide Delft3D January 2022

Based on Delft3D data temporal mapping in January 2022, it is known that there are two peak tides in one day. The first peak occurs in the time range 07.00 to 10.00 with height 185 cm to 215 cm. The peak of the second tide occurs at 18.00 to 21.00 with height 215 cm - 225 cm.

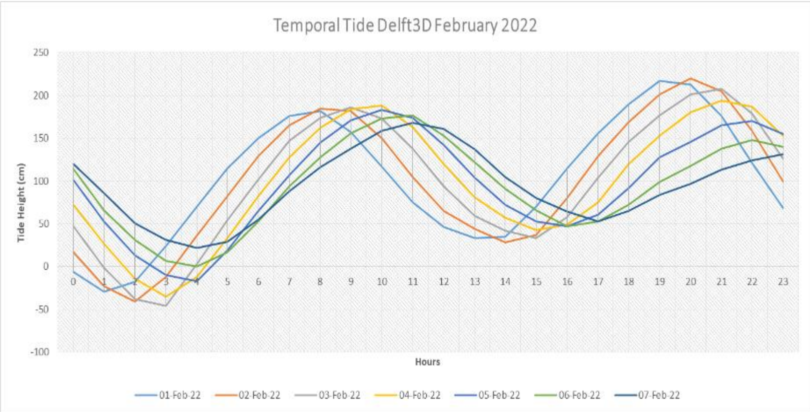


Figure 13. Temporal Tide Delft3D February 2022

Based on Delft3D data temporal mapping in February, it is known that there are two peak tides in one day. The first peak occurs in the time range 07.00 to 10.00 with height 175 cm to 185 cm. The peak of the second tide occurs at 19.00 to 21.00 with height 210 cm - 215 cm.

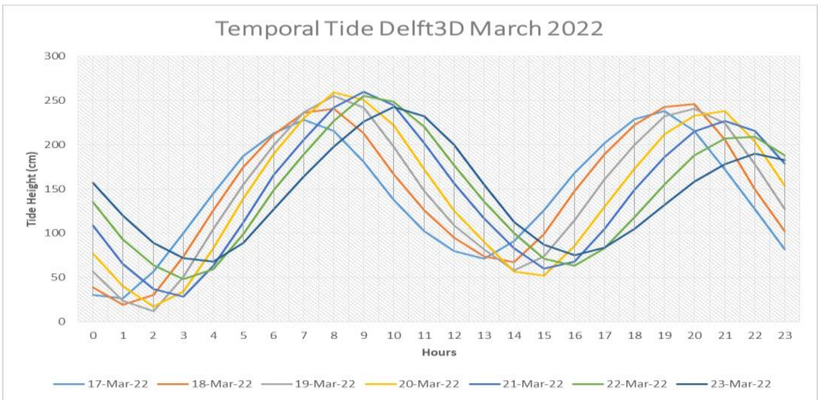


Figure 14. Temporal Tide Delft3D March 2022

Based on Delft3D data temporal mapping in March, it is known that there are two peak tides in one day. The first peak occurs in the time range 08.00 to 10.00 with height 250 cm to 255 cm. The peak of the second tide occurs at 19.00 to 21.00 with height 240 cm - 245 cm.

The wind has no effect on the increase height of tidal flood, but a significant wave height of 100 cm to 150 cm can increase the tidal flood by 10 cm.

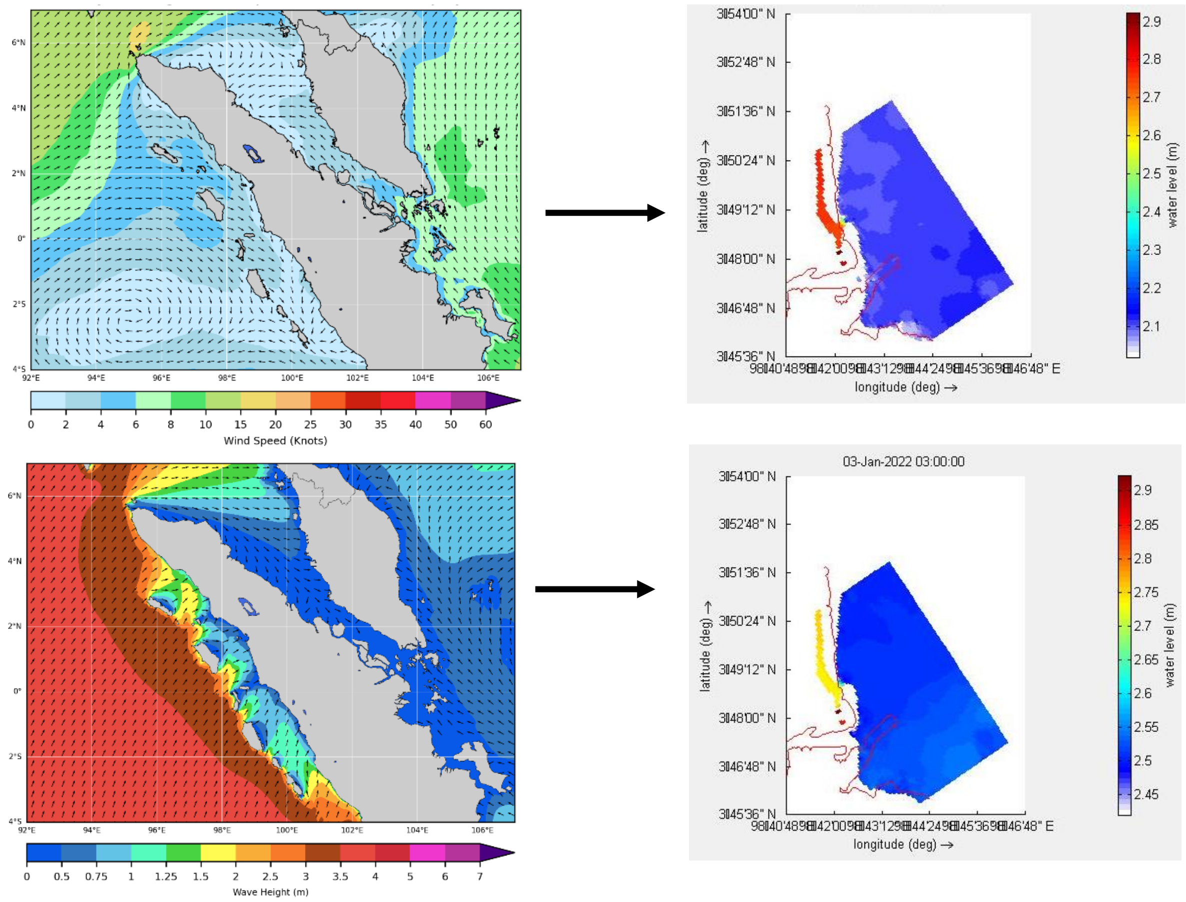


Figure 15. Effect of wind and waves on tidal flood

Verification is done to see the accuracy of the Delft3D model. Verification is carried out by comparing model data with tide observation data. The following is the result of model verification.

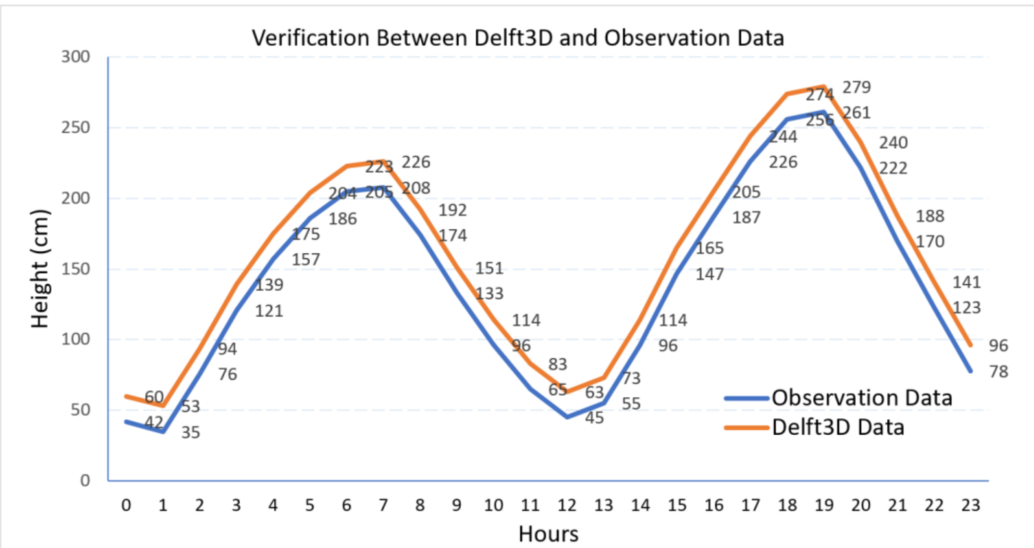


Figure 16. Verificaion Between Delft3D and Observation Data

Table 1. Verification Value

Month	Error (cm)	Coeffisien Correlation
January	24.5	0.93
February	23.5	0.94
March	22.5	0.92
Means	**23.5**	**0.93**

Verification results show that the Delft3D data is overestimated against the observation data. This shows Delft3D predictions exceed the height of the real tide event. The average error value is 23.5 cm. The correlation coefficient shows a positive value and is close to 1. This shows that the Delft3D data pattern with the observation data is quite good.

CONCLUSION

The conclusion based on the result of the analysis and discussion: (1) Based on the temporal mapping of the Delft3D model, the port and coastal areas of Belawan experience two high tides in one day where the high tide which results in tidal flooding occurs at the second high tide; (2) Wind speed does not have a significant impact on tidal flood increase. Significant wave height with a range of 125 cm to 150 cm gives the ability to increase the tidal flood height by 10 cm; (3) The error value resulting from the verification of the Delft3D model shows that the model overestimates the observed data. The error value is 23.5 cm. Delft3D is quite good at mapping the height of the tides, it can be seen from the small error; (4) The coefficient correlation value shows a positive value and is close to 1. This indicates that the model data pattern is similar to the observation data pattern, so Delft3D is quite good in terms of simulation.

RECOMMENDATION

The results of the Delft3D simulation will be better if the bathymetry input data is dense enough to produce more accurate nesting. The simulation will be better if the data used is longer. In future studies, it should be carried out in port and coastal areas that are directly facing the ocean so that the accuracy of Delft3D can be tested in each type of sea.

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