WAVE NUMERICAL MODEL OF SWELL AND SEA AT ROTE STRAIT

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***Abstract**: A spectral wave numerical simulation based on SWAN is used to model 10 years wave climate at Rote Strait, Nusa Tenggara Timur province. ERA5 reanalysis data of total wave and wind is used for model forcing. Simulation results show waves direction in Rote strait are coming from southeast and southwest. Waves direction at nearshore of southeast Timor island coast are coming from southeast because of refraction and diffraction. Waves height over 0.8 m occurs in 320 days in one year. 50 years wave return period calculated at 2.68 m height. Indeed, port development in Rote strait area need to consider the down time caused by waves and extreme wave forces in the design.*

Keywords: *Wave climate, SWAN, Rote strait*

INTRODUCTION

Wave is one important factor for designing a port. It is used to determine the port elevation, structure strength, layout, and port down time. Therefore, understanding wave climate in one site is crucial.

Wave condition in Indonesia is determined by monsoon season. With west monsoon occurs around December to February and the east monsoon occurs around June to August [1]. However, waves condition in south Indian ocean also determined by swell wave, where wave is generated far away and propagate to the shore. Hence, high swell can occur without local high wind.

Generally, wave data in Indonesia is rare. Historical wave analysis usually done by hindcasting wind data using Sverdruv Munk Bretschneider (SMB) methods [2]. Wave generation is calculated based on wind fetch, duration, and fully developed sea condition. However, swell wave is not calculated correctly when local wind data is used. In open sea, with high wind variability, swell wave may be not generated by local wind.

Wave hindcasting using numerical model is already common tools in today standard. As recent study shows in [3, 4, 5], wave climate model using a satellite derived data to perform long term wave climate analysis gives good results when compared with observation data sets. Moreover, in the presences of climate change, understanding wave climate become more crucial in future infrastructure development.

This study site is in Rote strait, Nusa Tenggara Timur. The strait is surrounded by Rote island, Semau island and Timor island with slight opening to the south (Figure 1). It also used as sailing route from Kupang to Rote island. Its location is prone to swell wave from south which can propagate into the strait.

In this paper, a numerical model based on spectral waves model SWAN [6] is used to simulate 10 year wave condition in Rote strait. This model uses ERA5 [7] reanalysis data for waves and winds for model forcing.

RESEARCH SIGNIFICANCE

This paper investigates 10 year wave climate in Rote strait using spectral wave model. This analysis considers swell and wind wave condition to obtain a seasonal and extreme wave condition.

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METHODOLOGY

This paper is organized firstly, by describing the model and setup parameter. Following step is to investigate the wave seasonal pattern and finally wave extreme analysis is performed.

A. MODEL DESCRIPTION

3rd generation SWAN model [6] in DELFT3D platform is used to simulate wave spectrum in this study. It solves waves action in spectral form. 3 nesting model domains are used in this simulation, extending to south Indian ocean as shown in Figure 2. The global model consists of 4028 grids with spatial dimension of 10 km, the regional model consists of 2444 grids with spatial dimension of 4.8 km and the local model consists of 5928 grids with spatial dimension of 1.2 km.

Model boundary condition for open boundary is setup using ERA5 reanalysis total wave data from year 2009 to 2018. A wind forcing also applied in the domain using single wind data from ERA5 reanalysis. Model is run for 10 years using quasi-stationary analysis.

B. ERA5 REANALYSIS DATA

Wave and wind forcing in this simulation uses the ERA5 reanalysis data [7] from 2009 to 2018. ERA5 Reanalysis has 0.25 x 0.25 for atmospheric data and 0.5 x 0.5 for ocean waves data. Figure 3 shows a comparison of ERA5 reanalysis wind data compared with Wind Data from Kupang weather station. Both data shows similar pattern in general. Wave rose for ocean waves data from ERA5 is shown in Figure 4.

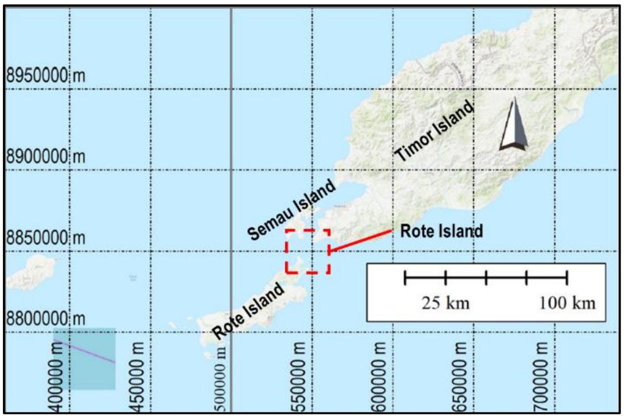

Figure 1 Study site

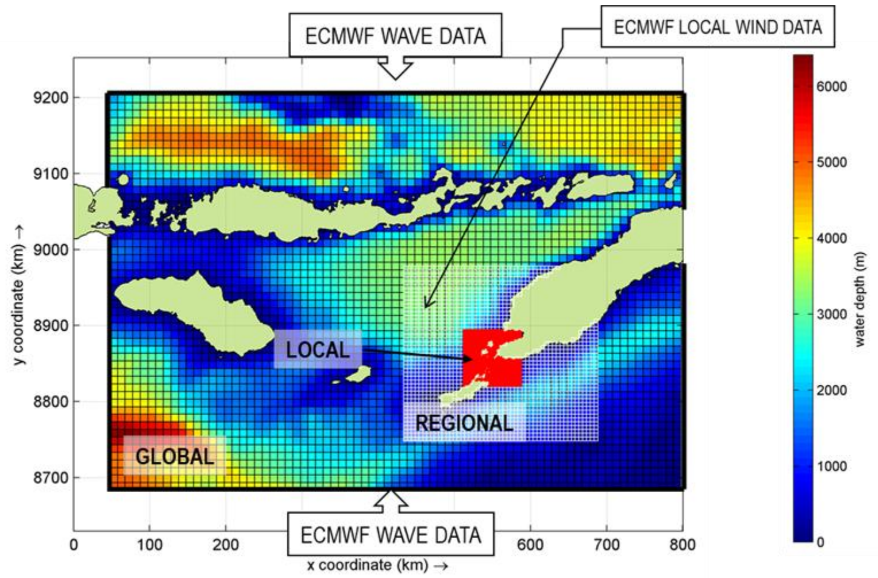

Figure 2 Grid configuration for wave model

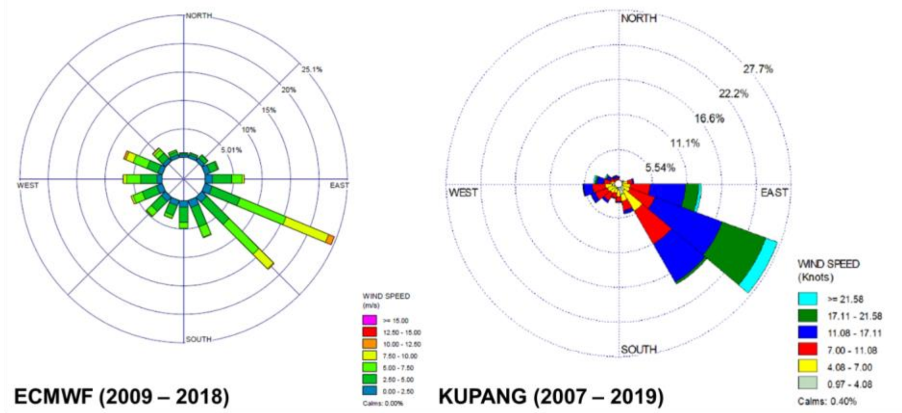

Figure 3 Comparison of wind data from ECMWF and Kupang weather station

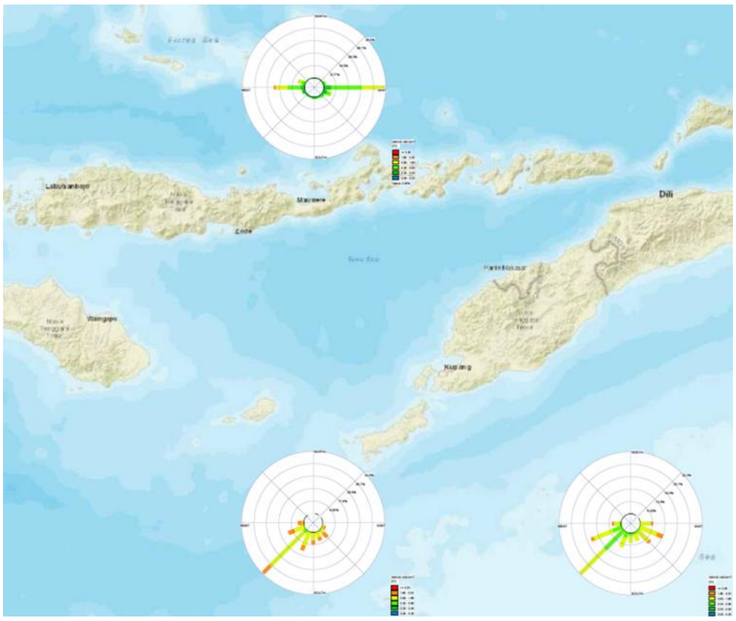

Figure 4 Wave rose plot for ECMWF wave data

C. EXTREME ANALYSIS

Extreme waves return period is calculated based on block maxima method with one year data block. The maximum data from each year then analyzed using 4 frequency distribution: lognormal, largest extreme value (LEV), Weibull and 3 parameter Weibull, to obtain the best distribution to represent the data. The best fit distribution then uses to calculate the extreme wave return period.

D. REFERENCE WAVES FOR PORT ACTIVITIES

Allowable wave height for port activities is based on ships size and wave direction. PIANC [8] gives a recommendation for limiting environmental operating conditions at quays and jetties (Table 1). The allowable significant wave height for loading and unloading operation is around 0.5 to 1.5 m. For larger ships, the allowable wave height can reach 2.5 m. In this research, a wave height of 0.8 m is considered as wave references for evaluating wave condition in Rote strait for port activities.

Table 1 Maximum wave height for each year

Description	Hs (m)
Forces longitudinal to the quay	
Oil tankers	
▪ < 30000 DWT	1.5
▪ 30000 DWT – 200000 DWT	2.0
▪ > 200000 DWT	2.5
Bulk carriers	
▪ Loading	1.5
▪ Unloading	1.0
Liquid Gas Carriers	
▪ < 60000 m^3	1.2
▪ > 60000 m^3	1.5
General cargo merchant ships, deep sea fishing boats and refrigerated vessels	1.0
Container ships, RoRo ships and ferries	0.5
Liners and Cruise ships	0.5
Fishing boats	0.6
Forces transverse to the quay	
Oil tankers	
▪ < 30000 DWT	1.0
▪ 30000 DWT – 200000 DWT	1.2
▪ > 200000 DWT	1.5
Bulk carriers	
▪ Loading	1.0
▪ Unloading	0.8
Liquid Gas Carriers	
▪ < 60000 m^3	0.8
▪ > 60000 m^3	1.0
General cargo merchant ships, deep sea fishing boats and refrigerated vessels	0.8
Container ships, RoRo ships and ferries	0.3
Liners and Cruise ships	0.3
Fishing boats	0.4

ANALYSIS AND DISCUSSIONS

A. WAVE SEASONAL PATTERN

Figure 5 to Figure 7 shows the snapshot of the model for global grid, regional grid, and the local grid. Two observation point uses to extract the wave time-series data. Simulation results are extracted at two observation points, one in the center of the Rote strait (OBS 01) and another one in nearshore of south-west coast of Timor island (OBS 02) where coastal infrastructures may be developed. Figure 8 shows the wave rose in OBS 01 and Figure 9 shows the wave rose at OBS 02.

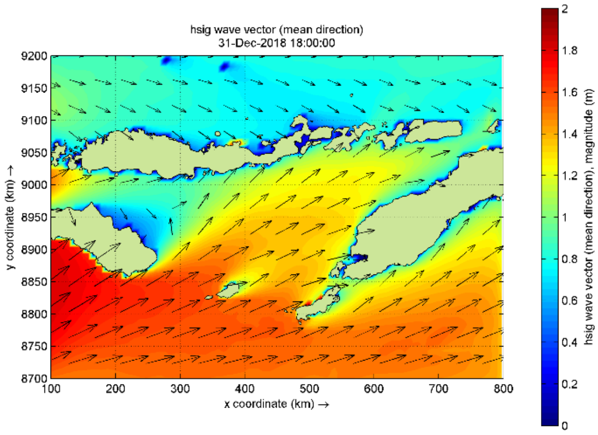

Figure 5 Snapshot of global wave model result

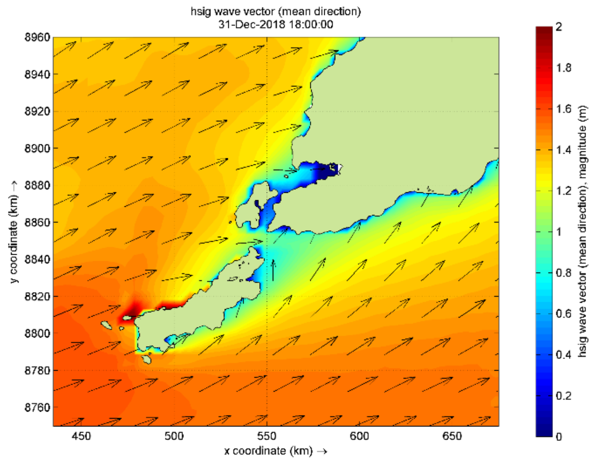

Figure 6 Snapshot of regional wave model result

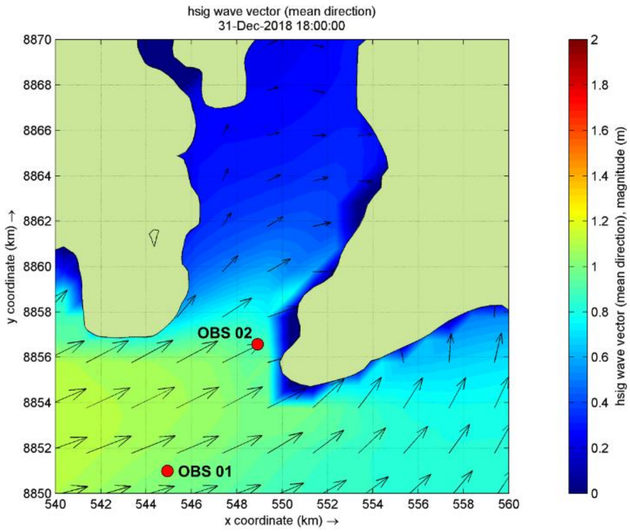

Figure 7 Snapshot of local wave model result and observation point location

Table 2 Wave class direction frequency at OBS 02

Directions / Wave Classes (m)	0.00 - 0.20	0.20 - 0.40	0.40 - 0.60	0.60 - 0.80	0.80 - 1.00	1.00 - 1.20	1.20 - 1.40	1.40 - 2.80	>= 2.80	Total
348.75 - 11.25 (N)	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
11.25 - 33.75 (NNE)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
33.75 - 56.25 (NE)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
56.25 - 78.75 (NEE)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
78.75 - 101.25 (E)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
101.25 - 123.75 (SEE)	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
123.75 - 146.25 (SE)	0.00%	0.00%	0.06%	0.06%	0.03%	0.00%	0.00%	0.00%	0.00%	0.15%
146.25 - 168.75 (SSE)	0.00%	0.01%	0.39%	1.13%	1.62%	1.16%	0.38%	0.10%	0.00%	4.78%
168.75 - 191.25 (S)	0.00%	0.00%	0.13%	0.35%	1.11%	2.02%	2.27%	2.43%	0.00%	8.30%
191.25 - 213.75 (SSW)	0.00%	0.00%	0.03%	0.93%	3.95%	6.01%	5.18%	6.45%	0.00%	22.55%
213.75 - 236.25 (SW)	0.00%	0.00%	0.23%	4.37%	9.74%	6.59%	2.35%	0.87%	0.00%	24.14%
236.25 - 258.75 (SWW)	0.00%	0.00%	0.13%	4.66%	13.47%	8.63%	5.16%	2.40%	0.00%	34.45%
258.75 - 281.25 (W)	0.00%	0.00%	0.01%	0.23%	0.69%	1.14%	1.22%	2.27%	0.00%	5.55%
281.25 - 303.75 (NWW)	0.00%	0.00%	0.00%	0.02%	0.02%	0.01%	0.00%	0.01%	0.00%	0.06%
303.75 - 326.25 (NW)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
326.25 - 348.75 (NNW)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sub-Total	**0.00%**	**0.01%**	**1.00%**	**11.74%**	**30.61%**	**25.55%**	**16.55%**	**14.53%**	**0.00%**	**100.00%**
Calms										0.00%
Missing/Incomplete										0.00%
Total										100.00%

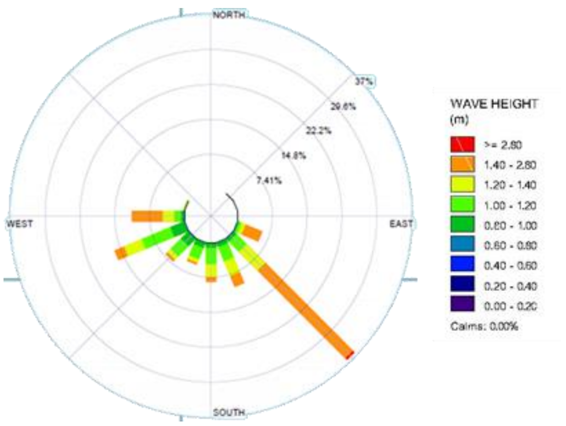

Figure 8 Wave rose at OBS 01

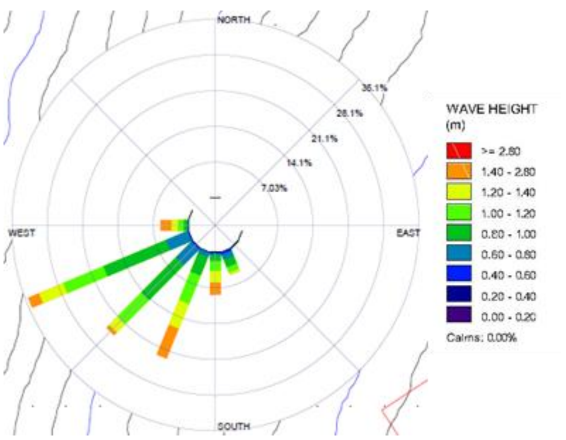

Figure 9 Wave rose at OBS 02

Wave direction at OBS 01 is dominated with a wave from direction southeast and southwest. At OBS 02, the wave direction is converged because of refraction and diffraction and coming from southwest.

A directional classification of wave height at Table 2 shows the wave from southwest (WSW, SW, SSW) for more than 81%. The wave height over 0.8 m occurs for 88% of wave occurrences at OBS 02. Even though it already sheltered because of Rote island and Timor island. It implies that port development near the south-western coast of Timor island will need a breakwater structure for shelter.

B. EXTREME WAVES

Extreme waves analysis is conducted for waves at OBS02. Table 3 shows the maximum waves height of each year for 10 year. Frequency distribution analysis shows the lognormal distribution fit the data best with p value of 0.730 and Anderson Darling normality test = 0.232 (Figure 10). Figure 11 shows the empirical cumulative distribution (ECDF) plot for lognormal distribution with scale of 0.102 and location of 0.77. Table 4 shows extreme waves height for each return period. For 50 year return period, the significant wave height is 2.68 m.

CONCLUSIONS

3rd generation SWAN model is used to simulate 10 year wave climate in Rote island, Nusa Tenggara Timur. The model consists of 3 nesting grids to optimize accuracy and computational resources. The wave simulation shows that the waves direction near the shore in south-western Timor island has converged with dominant direction from southwest. Waves near shore in Rote island is still high, with waves more than 0.8 m occurs more than 320 days a year (87.24% whole year). The extreme wave height for 50 years return period is reaching 2.68 m. Indeed, further verification is needed to verify the wave propagation into Rote strait. Therefore, port development in Rote strait area need to consider the down time caused by waves. The structural strength also needs to consider extreme wave forces in the design.

Table 3 Maximum wave height for each year

Years	Max of HS
2009	1.817
2010	2.366
2011	2.118
2012	2.246
2013	2.525
2014	2.327
2015	2.032
2016	1.908
2017	2.331
2018	1.991

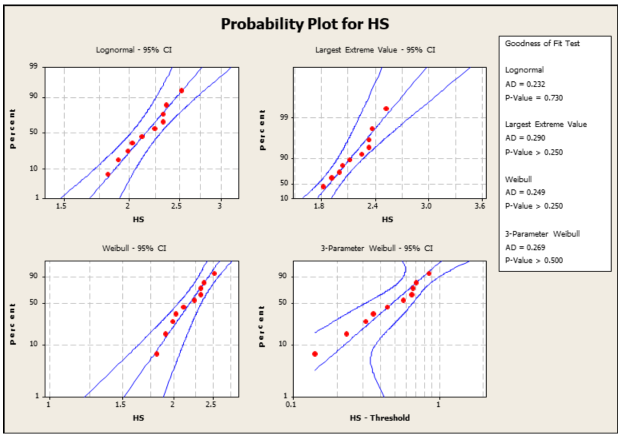

Figure 10 Frequency distribution fit for extreme waves

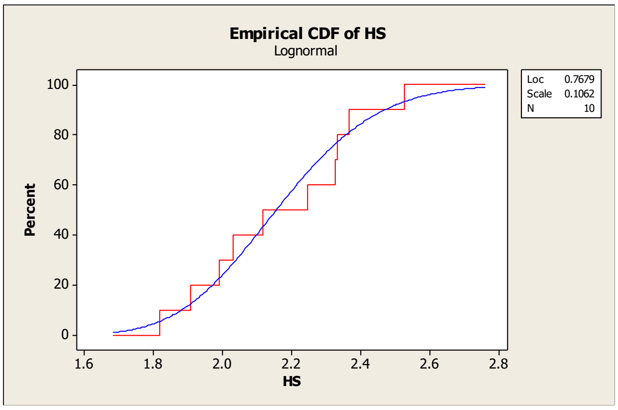

Figure 11 ECDF for wave height at OBS 02

Table 4 Wave return period at OBS 02

Return Period	Probability of Exceedance (%)	HS
1	99%	1.683
2	50%	2.155
5	20%	2.357
20	5%	2.567
25	4%	2.596
33	3%	2.632
50	**2%**	**2.681**
100	1%	2.759

ACKNOWLEDGMENTS

The authors are gratefully acknowledging the support from PT. ITS Tekno Sains. The authors also acknowledge European Centre for Medium-Range Weather Forecasts (ECMWF) and the scientist that provide the ERA5 data set.

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