Wind and Significant Wave Height at Indonesian Seas based on ERA5 Reanalysis Data from 2008 to 2018

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Abstract: Wind and waves are important elements in coastal engineering and oceanography. Research on variations of in-situ winds and wave's measurements is still very limited in Indonesia. Therefore, wind speed and significant wave height data from ERA5 reanalysis data, provided by the European Centre for Medium-Range Weather Forecast (ECMWF), and is used in this study. ERA5 data that has a spatial resolution of 0.25 ° x 0.25 ° is used to analyze correlation between wind speed and significant wave height at Indonesian seas in 2008 to 2018. The results show that wind speed and significant wave height in the closed water (inter-island in Indonesian archipelago) has a higher correlation compared to the Indonesian open sea that facing the Indian Ocean or Pacific Ocean.

1 INTRODUCTION

Wave height at sea level is very dependent on sea wind conditions. Understanding of tides and waves of sea water is a major requirement in the management of coastal areas (Yulius et al, 2017, Khoiri, 2015). Information about the sea wave itself is also very much needed in various maritime interests and activities. There are so many maritime studies that require this information, for example in research on breakwater structures (Torum et al, 2012). Significant wave height data is used to determine the speed of sediment transport on sandy beaches (Van Rijn, 2014). Significant wave height data is also needed in planning offshore buildings, for example in research on water breaking on ships (Dehghani et al, 2017) or effect of global warming on wave climate (Zikra et al, 2015).

Significant wave height is one of the important variables in disaster mitigation and coastal vulnerability using the CVI (Coastal Vulnerability Index) method (Serafim et al, 2019). This is used to estimate the vulnerability of coastal areas to the impacts of disasters that might occur. In the field of shipping, the height of sea waves is one of the important factors that are taken into account in determining the recommendations of ship shipping safety (Lutfiana and Tirono, 2013).

Analysis of significant wave height needs to be done because of the importance of information about significant wave heights needed for the benefit of research and maritime activities. One of the data that can be used in a significant wave height analysis is satellite data. Satellite data from the European Center for Medium Range Weather Forecast (ECMWF) will be used in this final project. ECMWF is considered to have reliable atmospheric data for research and evaluation (Hwang et al, 2019). ERA5, the fifth generation of ECMWF Reanalysis, is one of the global atmospheric reanalysis data products provided by ECMWF. ERA5 is an ECMWF product made to replace its predecessor, ERA-Interim. ERA5 data has a higher resolution than ERA-Interim (Hersbach and Dee, 2016). ERA 5 has a grid size of 0.25° x 0.25°, while the ERA-Interim has a grid resolution of 0.75° x 0.75°. Olauson (2018) concluded that ERA5 has a lower error value and has more advantages than MERRA-2 (Olauson, 2018). Because of the various advantages of ERA5, the ERA5 data will be used in this research to analysis the variation of significant wave height (*Hs*) and wind speed in Indonesian waters.

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2 DATA

The wind and wave data used in this study is obtained from ECMWF ERA5 (https://www.ecmwf.int). Data obtained is hourly data in Indonesia seas during 2008 to 2018. The location points reviewed are:

1. Western Sumatera, Indian Ocean (3,75° S and 99,75° E)
2. Sunda Strait (6° S and 105,75° E)
3. Southern Java (8° S and 110° E)
4. Malaka Strait (3,75° N and 99,75° E)
5. Java Sea (6,75° S and 112,5° E)
6. Flores Sea (6,75° S and 121,5° E)
7. Makassar Strait (1,5° S and 117,5° E)
8. Halmahera Sea (1,5° N and 129,25° E)
9. Northern Papua (0,25° Sand 135° E)
10. Jayapura (2,25° Sand 140,5° E)

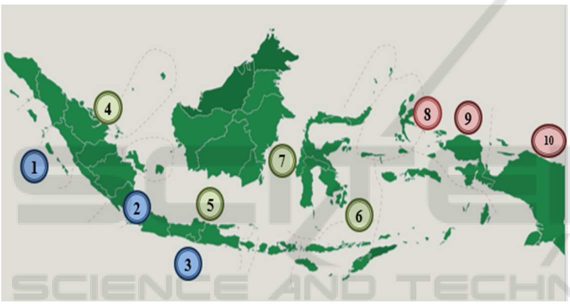

Figure 1: Reviewed location points in Indonesian Seas.

These locations are divided into 3 zones, namely open water zone facing the Indian Ocean (locations 1, 2 and 3), sheltered water zone (locations 4, 5, 6, and 7), and open water zone facing the Pacific Ocean (locations 8, 9 and 10).

3 RESULT AND DISCUSSION

3.1 Variation of Wind Speed

The trend of wind speed on monthly average during 2008-2018 can be seen in Table 1. In Southern Sumatera, the statistically significant trend is only appeared in September's with monthly maximum wind speed of 0.193 $m.s^{-1}$/year. In Sunda Strait, the monthly maximum wind speed has a significant increasing trend of 0.176 $m.s^{-1}$/year. Monthly maximum wind speed and mean wind speed in Southern Java have a significant increasing trend in November and December. The trend of monthly maximum wind speed in Southern Java has a significant increasing

The trend of monthly maximum wind speed in November is 0.279 $m.s^{-1}$/year and in December is 0.364 $m.s^{-1}$/year. The monthly mean wind speed trend in November is 0.104 $m.s^{-1}$/year and in December is 0.126 $m.s^{-1}$/year. Monthly maximum wind speed in Malaka Strait has a value of increasing trend at 0.191 $m.s^{-1}$/year in February, 0.201 $m.s^{-1}$/year in April, 0.208 $m.s^{-1}$/year in November, and 0.255 $m.s^{-1}$/year in December. Whereas the monthly mean wind speed in Malaka Strait has a significant increasing trend in January (0.147 $m.s^{-1}$/year), February (0.066 $m.s^{-1}$/year), May (0.051 $m.s^{-1}$/year), June (0.046 $m.s^{-1}$/year), September (0.174 $m.s^{-1}$/year), October (0.147 $m.s^{-1}$/year), and December (0.112 $m.s^{-1}$/year). The calculation of monthly mean wind speed trend in Java Sea shows that there is no significant trend every month throughout the period of 2008-2018. Meanwhile the monthly maximum wind speed trend value in Java Sea in June has a significant increasing trend of 0.095 $m.s^{-1}$/year. The calculation of maximum wind speed and monthly mean trend in Flores Sea shows that there is no significant trend every month throughout 2008-2018. The monthly average wind speed in Makassar Strait in December had a significant increasing trend of 12.52 $m.s^{-1}$/year. The trend was also significantly increase by 0.125 $m.s^{-1}$/year in March, in contrast there was no significant monthly maximum wind speed trend value in Makassar Strait throughout the years of 2008-2018. Moreover, the monthly maximum wind speed in Halmahera Sea has a significant decreasing trend in May (-0.375 $m.s^{-1}$/year) and a significant increasing trend (0.172 $m.s^{-1}$/year) in October. The monthly mean wind speed in Halmahera Sea has a significant decreasing trend in May (-0.07 $m.s^{-1}$/year) and a significant increasing trend in March and April of 0.117 $m.s^{-1}$/year and 0.039 $m.s^{-1}$/year.

Furthermore, monthly maximum wind speed in Southern Papua does not have a significant trend throughout 2008-2018. The monthly mean wind speed in Utara Papua has a significant increasing trend in February by 0.099 $m.s^{-1}$/year, 0.081 $m.s^{-1}$/year in April, 0.091 $m.s^{-1}$/year in November, and 0.113 $m.s^{-1}$/year in December. Monthly maximum wind speed in Jayapura in October has a decreasing trend of -0.115 $m.s^{-1}$/year. The mean monthly wind speed in Jayapura has an increasing trend in February (0.136 $m.s^{-1}$/year), November (0.079 $m.s^{-1}$/year), and December (0.093 $m.s^{-1}$/year). Wind rose at 10 reviewed location points during 2008-2018 can be seen in Figure 3.

Table 1: Monthly mean wind speed trend 2008-2018.

Month	Monthly Mean Wind Speed Trend ($m.s^{-1}$/year)									
	1	2	3	4	5	6	7	8	9	10
January	0.095	0.029	-0.024	0.147	-0.074	-0.104	0.057	-0.003	-0.043	-0.068
February	-0.111	-0.060	-0.016	0.066	-0.081	-0.100	0.035	0.052	0.099	0.136
March	-0.063	-0.058	-0.018	0.004	0.042	0.121	0.074	0.117	0.071	0.081
April	0.018	-0.013	0.002	0.035	0.022	-0.063	0.009	0.039	0.081	0.056
May	-0.060	-0.015	0.046	0.051	0.059	0.032	-0.019	-0.070	-0.007	0.017
June	-0.041	0.004	0.019	0.046	0.007	-0.007	-0.029	-0.027	-0.013	0.029
July	-0.029	0.005	-0.015	0.073	0.050	-0.004	0.028	0.073	-0.015	-0.068
August	0.014	0.034	0.003	0.085	0.023	-0.006	0.097	0.120	-0.019	-0.033
September	0.084	-0.019	-0.025	0.174	0.061	0.052	-0.011	0.090	-0.026	-0.018
October	0.028	0.009	-0.001	0.147	0.021	-0.015	0.043	0.068	-0.018	-0.040
November	0.084	0.025	0.104	0.080	0.070	0.047	0.083	0.061	0.091	0.079
December	0.037	0.057	0.126	0.112	0.100	-0.007	0.125	0.060	0.113	0.093

Table 2: Monthly mean significant wave height trend 2008-2018.

Month	Monthly Mean Significant Wave Height Trend (m/year)									
	1	2	3	4	5	6	7	8	9	10
January	0.014	0.012	0.000	0.002	-0.013	-0.018	0.006	0.001	-0.012	-0.009
February	-0.008	-0.017	-0.005	0.007	-0.015	-0.024	0.007	0.013	0.014	0.015
March	0.000	-0.010	0.004	0.001	0.008	0.021	0.007	-0.004	-0.004	-0.001
April	-0.002	-0.001	0.006	0.003	0.003	-0.008	0.002	0.006	-0.005	0.006
May	0.004	-0.002	0.005	-0.004	0.012	0.010	0.000	-0.004	-0.010	-0.003
June	0.013	0.005	0.007	0.003	0.000	0.007	-0.003	-0.008	0.003	-0.004
July	0.019	0.006	0.024	-0.001	0.006	0.000	0.001	0.010	-0.001	0.001
August	0.019	0.004	0.011	-0.001	0.001	-0.003	0.012	0.013	0.001	-0.002
September	0.005	-0.001	-0.006	0.003	0.011	0.007	-0.001	0.014	0.011	0.002
October	0.006	0.002	-0.003	0.002	0.003	-0.001	0.007	0.018	0.053	0.010
November	0.009	-0.001	0.009	0.002	-0.002	-0.003	-0.001	0.007	0.003	0.010
December	0.014	0.014	0.016	0.010	0.016	0.008	0.008	0.001	0.013	0.005

3.2 Variation of Significant Wave Height

Significant monthly mean wave height in Western Sumatera has a significant increasing trend in August at 0.019 m/year, while monthly maximum significant wave height in Southern Sumatera has an increasing significant trend in July by 0.081 m/year and 0.062 m/year in August. The calculation of the maximum monthly significant wave height trend in Sunda Strait shows that there is no significant trend every month throughout the years 2008-2018, while the monthly significant wave height trend value in Sunda Strait, July, has a significant increasing trend of 0.006 m/year.

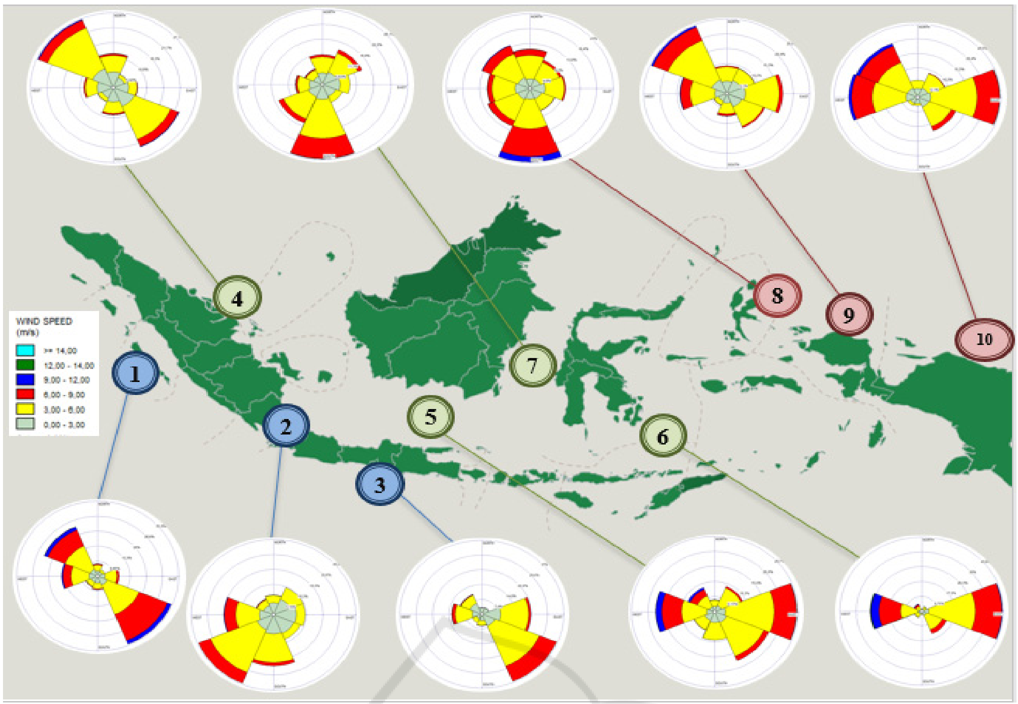

Figure 3: Wind rose at 10 reviewed location points during 2008-2018.

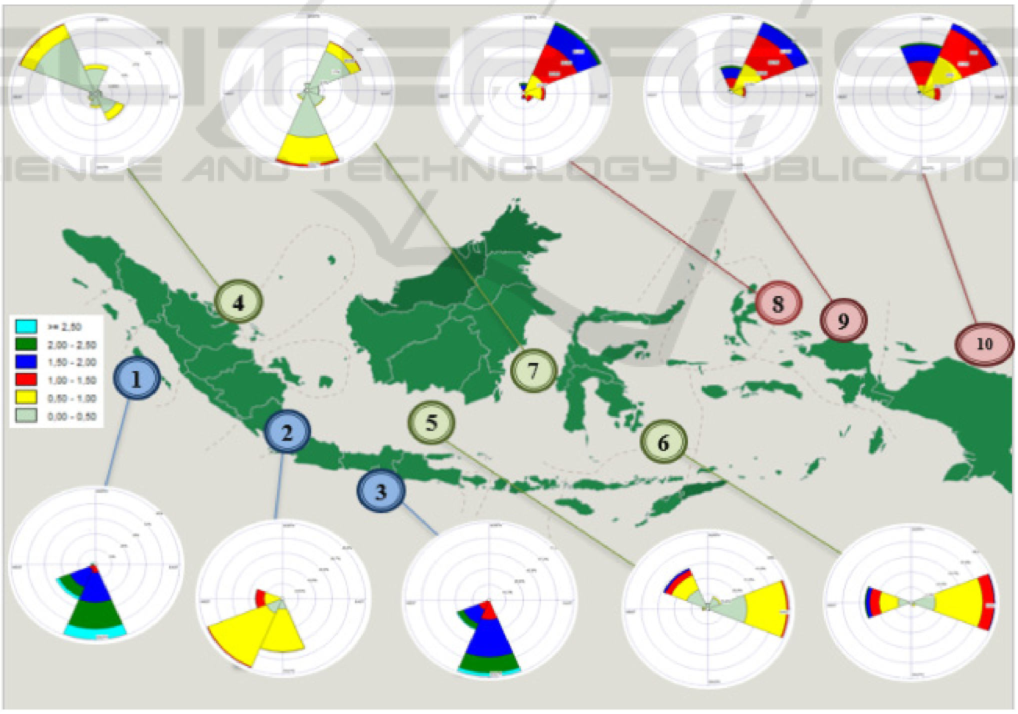

Figure 4: Wave rose at 10 reviewed location points during 2008-2018.

Monthly maximum significant wave height in Southern Java has a significant increasing trend of 0.05 m/year in May, 0.05 m/year in August, and 0.068 m/year in December.

Furthermore, the monthly mean significant wave height in Southern Java has a significant increasing trend in July of 0.024 m/year and December of 0.016 m/year. In February, there was a significant

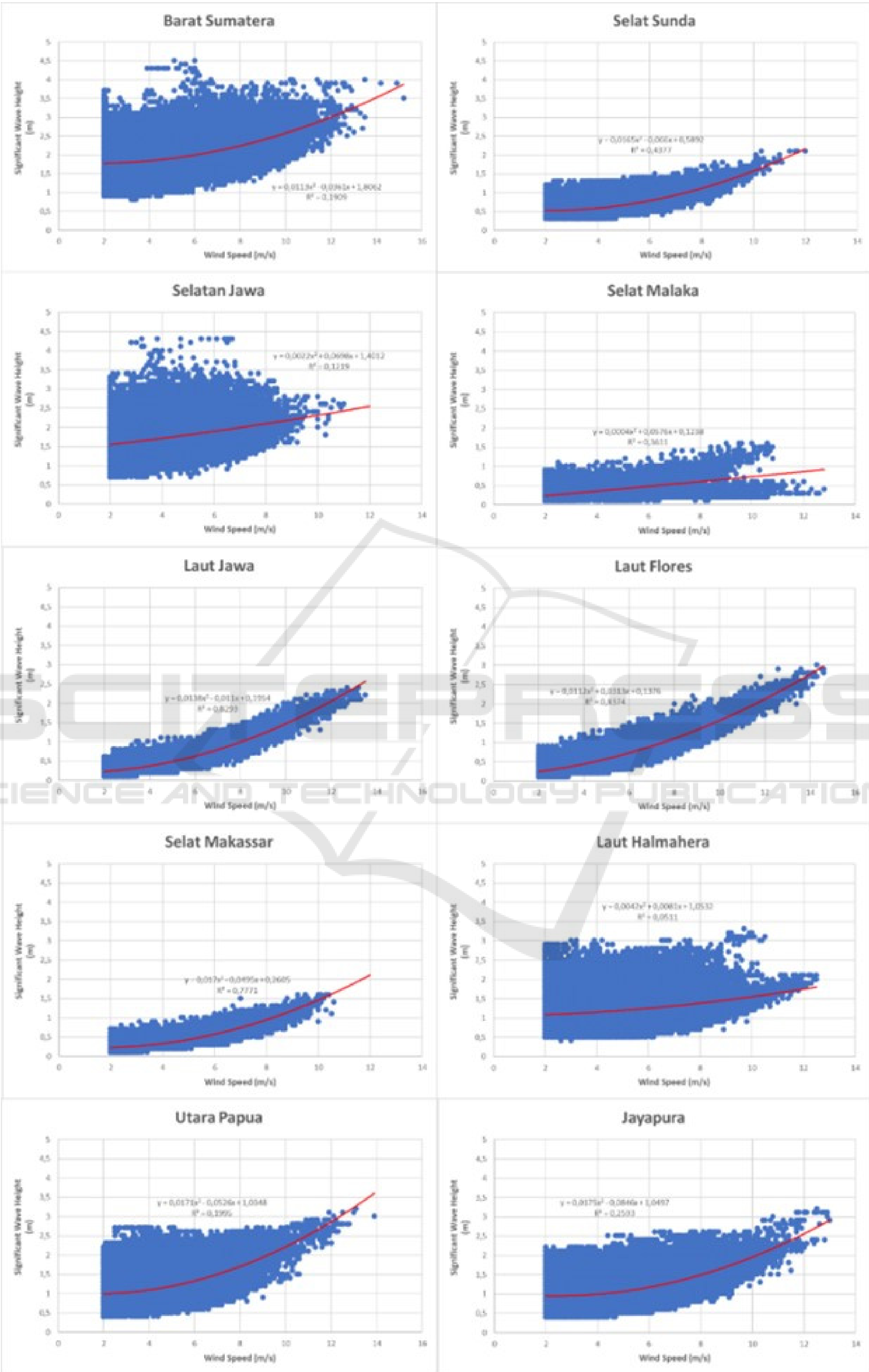

Figure 5: Regression graph of wind speed and significant wave height at Indonesian Seas.

increasing trend in Malaka Strait both at monthly maximum and mean significant wave height. For the significant monthly mean wave height, the significant trend is calculated by 0.007 m/year, while the maximum monthly mean wave height has a significant trend of 0.025 m/year. The calculation the monthly maximum significant wave height trend in Java Sea shows that there is no significant trend every month throughout the years 2008-2018. The trend value of monthly mean significant wave height in Java Sea has a significant increasing trend of 0.012 m/year in May. Monthly maximum significant wave height in Makassar Strait has a significant increasing trend of 0.028 m/year in August. Monthly mean significant wave height in Makassar Strait has a significant increasing trend by 0.008 m/year in December. The calculation of the monthly significant wave height trend in Northern Papua shows that there is no significant trend that occurs every month throughout 2008-2018. The trend of the maximum monthly significant wave height in Northern Papua in December has a significant decreasing trend of -0.055 m/year. There is no significant trend of monthly significant wave height in Jayapura during 2008-2018. Monthly maximum significant wave height in Jayapura has a significant decreasing trend in June and August, each at -0.054 m/year and at -0.03 m/year. The calculation of the monthly maximum and the monthly mean significant wave height trend in Flores Sea and Halmahera Sea shows that the trend that exists every month throughout the years 2008-2018 is not statistically significant. The calculation of monthly mean significant wave height trend in 11 years can be seen in Table 2. Wave rose from 10 reviewed location points during 2008-2018 can be seen in Figure 4.

3.3 Relationship of Wind Speed and Wave Height

The relationship of wind speed and significant wave height in Indonesia during 2008-2018 at each reviewed location point has a positive correlation. It can be seen from Table 3 that the sheltered water of Indonesian archipelago, namely Malaka Strait, Java Sea, Flores Sea, and Makassar Strait, have a determination coefficient above 0.3. Even more, Java Sea and Flores Sea each has a determination coefficient 0.75. On the other hand, in waters facing the ocean, Western Sumatera, Southern Java, Halmahera Sea, Northern Papua, and Jayapura, the determination coefficient is below 0.3. This means that the relationship of significant wave height and wind speed in those waters is not as high as the relationship in the sheltered waters. Sunda Strait which is categorized as an open water in this paper turns out to have characteristics that tend to follow the characteristics of sheltered waters which have a quite high correlation between wind speed and significant wave height with determination coefficient of 0.438.

Regression chart of the correlation between wind speed and significant wave height in all reviewed location points can be seen in Figure 5. The regression method used is quadratic regression or polynomial order 2.

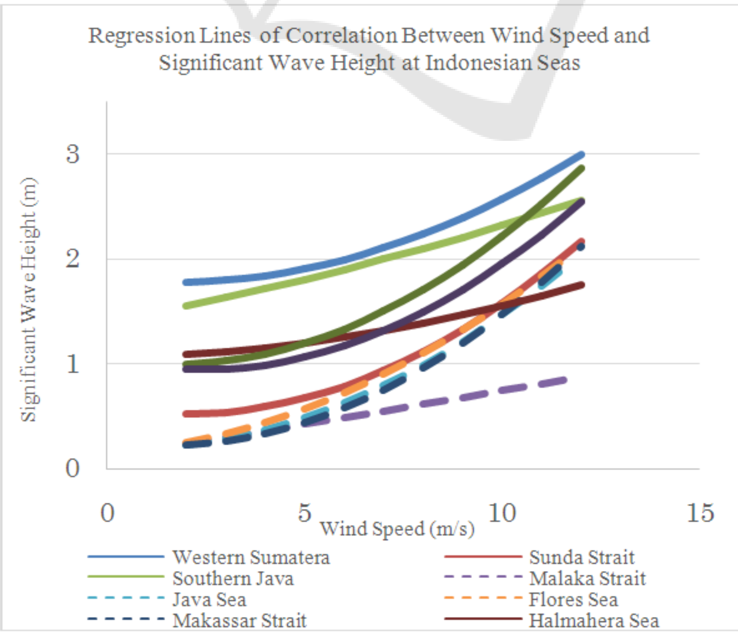

Figure 6: Regression line of wind speed and significant wave height correlation at 10 reviewed location points in 11 years.

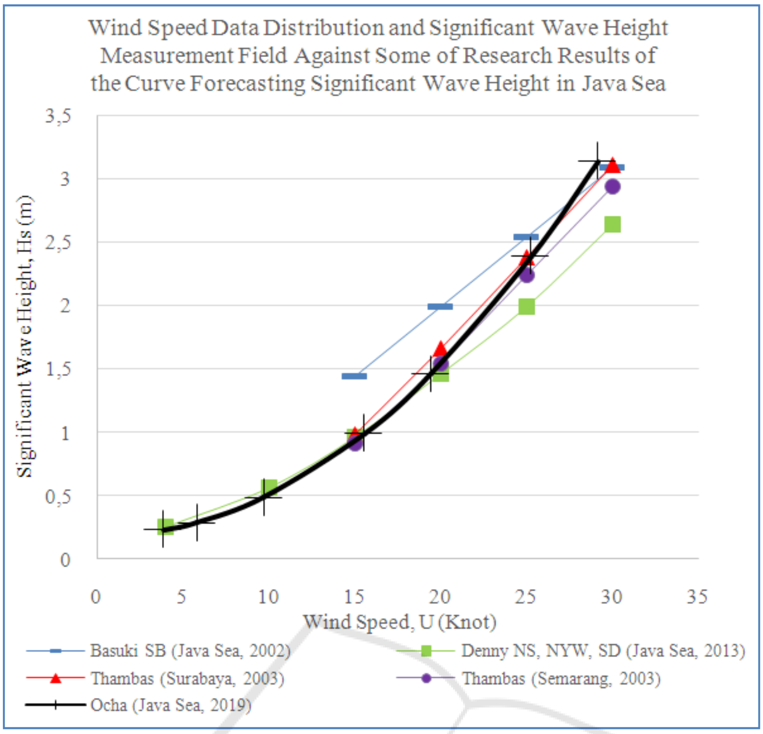

Figure 7: Wind speed data distribution and significant wave height of ERA5 data compared to some studies regarding wave forecasting in Java Sea.

It can be seen in Figure 6 that the regression lines of sheltered waters (Malaka Strait, Java Sea, Flores Sea, and Makassar Strait) are below the open water regression line, which means that the significant wave height in sheltered waters is lower than in open waters. The regression lines of sheltered waters are also more curved than open waters regression lines. It means that the correlation between wind speed and significant wave height in sheltered waters is higher than the correlation of wind speed and significant wave height in open waters. The graph only compares the wind speed and significant wave height without taking into account of the direction of the wind and wave itself. Therefore, the graph cannot be used as a reference in determining the significant wave height based on wind speed or vice versa.

Figure 7 shows the distribution data of wind speed and significant wave height from ERA5 compared to direct measurement field data on some studies of wave height forecasting in the Java Sea from Thambas and Yuwono (2003), Denny et al (2017), Basuki (2000). As seen in Figure 7, the wind speed data range is limited between 5 knots to 30 knots. Figure 7 indicated that ERA5 data has similar trend as other studies in the Java Sea.

4 CONCLUSIONS

Conclusions that can be obtained in this paper include:

1. Monthly mean wind speed at Indonesian Seas is about 2 m/s to 9 m/s. Monthly maximum and monthly mean wind speed at each reviewed location points have statistically significant trend, except at Flores Sea.
2. Monthly mean significant wave height at Indonesian Seas is about 0,2 m to 2,8 m. Monthly maximum and monthly mean significant wave height at each reviewed location points have statistically significant trend, except at Flores Sea and Halmahera Sea.

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