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Analysis of Influence of Cyclone Seroja on Wave Height and Tide in the Indian Ocean

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ABSTRACT

Tropical Cyclone Seroja, which occurred in the Indian Ocean, was characterized by maximum wind speeds of 70 knots. As part of the impact assessment associated with the cyclone, wave height observations were conducted along its track and tidal examinations were carried out at Cape Cuvier and Kupang tidal stations. Therefore, this research aims to analyze the relationship between wind speed and wave height, as well as the impact of Cyclone Seroja on waves and tide. The results showed that Cyclone Seroja reached a very high intensity with maximum wind speeds of 70 knots and maximum wave height of 14.24 meters on April 11, 2021, at 06:00 UTC. Regression analysis showed an R-squared value of 0.716, indicating that 71.6% of the variation in wave height can be explained by wind speed. The correlation value of 0.846 indicated a strong relationship between wind speed and wave height. This research also analyzed the changes in residual tide height at Cape Cuvier tidal station on April 11, 2021, with a maximum residual height of 0.57 meters. Wave height propagation from wave station 1487 significantly influenced the residual tide value at Cape Cuvier, with wave height of 11.790 meters and a propagation speed of 40.42 km/h. At Kupang tidal station, there was a residual height change of up to 0.27 meters, caused by influence of low pressure around wave station 239, with an average pressure of 1001 pHa and an average wave height of 3.89 meters, propagating towards the Kupang tidal station during the formation phase of Tropical Cyclone Seroja.

Keywords: Cyclone; Seroja; Wave; Tide; Indian Ocean*.*

ABSTRAK

Siklon Tropis Seroja adalah siklon tropis yang terjadi di perairan Samudera Hindia dengan kekuatan angin maksimum mencapai 70 knot. Pengamatan tinggi gelombang dilakukan di stasiun gelombang yang berada di sepanjang lintasan siklon Tropis Seroja dan pengamatan pasang surut dilakukan di stasiun pasang surut Cape Cuvier dan stasiun pasang surut Kupang. Penelitian ini bertujuan untuk menganalisis hubungan antara kecepatan angin dan tinggi gelombang serta pengaruh Siklon Tropis Seroja terhadap tinggi gelombang dan pasang surut. Hasil penelitian menunjukkan bahwa pada tanggal 11 April 2021 pukul 06.00 UTC, siklon Seroja mencapai intensitas yang sangat tinggi dengan kecepatan angin maksimum mencapai 70 knot dan tinggi gelombang maksimum mencapai 14.24 meter. Analisa Regresi menunjukkan bahwa R^2 sebesar 0.716, yang dapat diartikan bahwa 71.6% dari variasi tinggi gelombang dapat dijelaskan oleh kecepatan angin. Nilai korelasi sebesar 0.846, menunjukkan adanya hubungan yang kuat antara kecepatan angin dan tinggi gelombang. Penelitian ini juga menganalisis perubahan tinggi residual pasang surut pada stasiun pasang surut Cape Cuvier yang terjadi pada tanggal 11 April 2021 dengan tinggi residual maksimum 0.57 meter. Perambatan tinggi gelombang dari stasiun gelombang 1487 mempunyai pengaruh yang signifikan terhadap tinggi nilai residu pasang surut Cape Cuvier, dengan tinggi gelombang 11.790 meter dengan kecepatan perambatan gelombangnya 40.42 km/jam. Stasiun pasang surut Kupang mengalami perubahan tinggi residual mencapai 0.27 meter yang disebabkan oleh pengaruh tekanan rendah disekitar stasiun gelombang 239 dengan rata-rata 1001 pHa dan tinggi gelombang rata-rata 3.89 meter yang merambat menuju stasiun pasang surut Kupang pada saat tahap pembentukan Siklon Tropis Seroja.

Kata Kunci : Siklon, Seroja, Gelombang, Pasang Surut, Samudera Hindia

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1. Introduction

A tropical cyclone is a natural phenomenon that arises when a synoptic-scale low-pressure system develops over warm tropical waters, resulting in the formation of an atmospheric vortex. The tropical cyclone is distinguished by the presence of a conventional cloud cluster and maximum wind speeds exceeding 34 knots. This cyclone typically lasts for three to eight days and comprises three stages, formation, maturity, and weakening (Syaifullah, 2015). The impact of tropical cyclone extends within a radius of 2° to 4° from the center, while storm formation patterns can extend to a radius of 12° or more (Sani & Marzuki, 2015).

The Indian Ocean, located in the southern hemisphere, is recognized as a vulnerable region for tropical cyclone. The impact of tropical cyclone is influenced by various factors, including their position and intensity, which depend on air circulation patterns in the Indonesian region (Perawiska & Adriat, 2018). Six primary factors contribute to the formation of tropical cyclone, namely warm sea surface temperatures, high humidity levels in the lower and middle troposphere, the Coriolis force, weak vertical wind shear, atmospheric instability, and significant relative cyclonic vorticity in the lower troposphere (Klotzbach et al., 2017). These disturbances trigger natural hazards, including heavy rainfall and floods (Baranowski *et al*., 2020).

Tropical Cyclone Seroja is among the first tropical cyclone to significantly impact Indonesian territory and is particularly known for its strength, which is close to Timor Island (Latos et al., 2023). The impacts of Tropical Cyclone Seroja encompass potential hydrometeorological disasters, such as strong winds, intense and sustained rainfall leading to floods and landslides (Makmur et al., 2021). Additionally, it also influences wave height and tide, which vary based on the intensity and direction of cyclone.

Seroja emerged as a tropical disturbance near Rote Island, Indonesia, on April 2nd. As time passed, the disturbance gradually intensified, eventually reaching Category 1 status as a tropical cyclone on April 4th. At 20:00 UTC, the *Tropical Cyclone Warning Centre* (TCWC) in Jakarta officially named it Seroja (TCWC, 2021). From April 6th to 7th, Tropical Cyclone Seroja experinced a weakening phase while moving southwestward as a tropical disturbance. Subsequently, between April 8th and 9th, Seroja interacted with another tropical disturbance, resulting in temporary strengthening. On April 10th, cyclone abruptly shifted towards the southeast and rapidly approached the coast of Western Australia. By April 11th, Seroja had intensified to severe Category 3 tropical cyclone status as it made landfall south of Kalbarri around 20:00 Australian Western Standard Time (AWST) (Earl-Spurr, 2022).

A comprehensive review of published scientific articles, there is no specific article addressing the relationship between Tropical Cyclone Seroja and tidal elevation changes. According to (Jannatunnisa & Trismidianto, 2022; Sofiati & Putranto, 2020; Susandi et al., 2023), tropical cyclones resulting a significant increase in intensity of sea-atmospheric parameters such as rainfall, significant wave height, and wind direction & speed, but decreased for sea level pressure. As a result of Tropical Cyclone Seroja, significant changes occur in marine parameters, including cooling of sea surface temperature, increase in chlorophyll-a, and induced upwelling phenomenon (Avrionesti et al., 2021). This research aims to bridge that gap by examining influence of Tropical Cyclone Seroja on wave characteristics and significant changes in tidal height, such as the transformation of waves from normal to extreme, for example, a drastic increase in height from 0.5 m to 6-14 m during a cyclone in the Indian Ocean, as well as the occurrence of irregular spikes higher than the normal tidal height.

2. Material and Methods

The present research used descriptive statistical and correlation analyses, alongside simple linear regression methods, to explore the connection between Tropical Cyclone Seroja and wave height (Bevans, 2020). The primary objective of this research is to investigate how Tropical Cyclone Seroja affects wave height and tidal changes in the vicinity of its track.

2.1. Research Sites

Based on Figure 1, the present research was conducted in the Indian Ocean at coordinates ranging from 8° to 38° S and 105° to 125° E. In addition to collecting data on Cyclone Seroja, the research also focused on gathering wave and tidal data. Wave data is obtained from stations located along the track of Cyclone Seroja. Meanwhile, tidal data is collected from the nearest stations to the path of cyclone, namely Cape Cuvier and Kupang in Australia and Indonesia, respectively. Cape Cuvier is a station located in the southwestern coastal region of Australia at coordinates 24.2206 S to 113.3969 E, while Kupang is located on the eastern coast of Indonesia at coordinates 10.1953 S to 123.5272

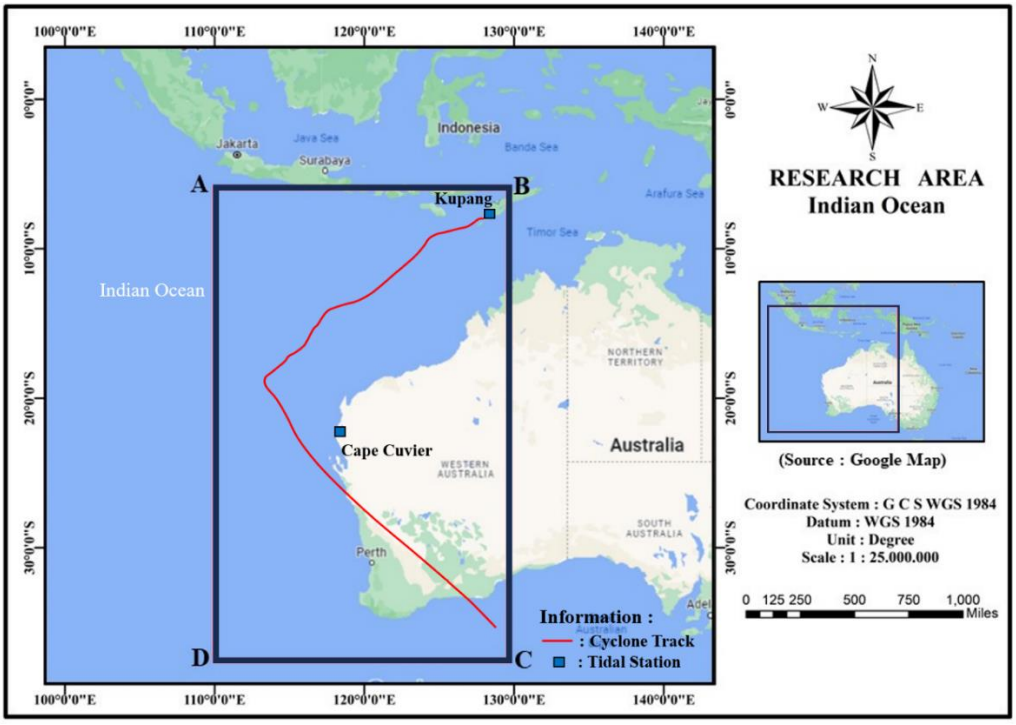


Figure 1. Map of the location of research objects in the Indian Ocean
(Source: https://www.google.com/maps/@-10.739471,125.7677436,3.31z?entry=ttu)

E. These stations were selected due to their proximity to the track of Cyclone Seroja. The data collected from these stations are used as primary data in this research.

2.2. Research Datasets

This research incorporates primary and secondary data collected from April 3rd to 13th, 2021. The primary data sources include Cyclone Seroja data obtained from the International Best Track Archive for Climate Stewardship (IBTrACS), available at https://ibtracs.unca.edu/. Additionally, tidal data is gathered from the Geospatial Information Agency (BIG) and the Intergovernmental Oceanographic Commission (IOC) through https://www.ioc-sealevelmonitoring.org/. Barometric pressure data is sourced from Ventusky at https://www.ventusky.com/. Complementing the primary data, wave height information is obtained as secondary data from Climate Copernicus, through https://cds.climate.copernicus.eu.

2.3. Simple Linear Regression Equations

According to Uyanık & Güler (2013), Regression is a measurement tool used to assess the correlation between variables. Regression analysis studies relationships represented in mathematical equations to show how variables are interrelated. If it only compares one prediction variable with one outcome variable, it is called simple regression. However, if it compares more than one variable, it is called multiple regression.

Simple Linear Regression is a Statistical Method to test the extent of the causal relationship between the causal factor variable (X) and the outcome variable (Y). Variable X is referred to as the predictor, while Y is referred to as the Response.

Simple linear regression equation model:

$$Y = a + bX \quad \ldots\ldots\ldots (1)$$

Description:
Y = dependent variable
X = independent variable
a = intercept
b = regression coefficient / slope

$$b = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} \quad \ldots\ldots\ldots (2)$$

$$a = \frac{\sum Y \sum X^2 - \sum X \sum XY}{n\sum X^2 - (\sum X)^2} \quad \ldots\ldots\ldots (3)$$

Simple Regression Coefficient Test (t test). This test is used to determine whether the independent variable (X) has a significant effect on the dependent variable (Y). Significant means

that the influence that occurs can apply to the population (can be generalized).

The statistical hypothesis:

Ho: β = 0 (X has no effect on Y)
H1: β ≠ 0 (X has an effect on Y)

The formula for t count in regression analysis is as follows:

$$t\ count = \frac{b}{Sb} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \quad \ldots\ldots (4)$$

Description:
b = regression coefficient
Sb = standard error
r = simple correlation coefficient
n = number of data or cases

The coefficient of determination, denoted as R^2 in simple regression, is a valuable metric typically expressed as a percentage (%). It helps assess the extent to which variable x contributes to the variation, whether it leads to an increase or decrease, in variable y. This coefficient plays a crucial role in predicting and evaluating the collective influence of variable x on y (Kurniawan & Budi, 2016).

2.4. Correlation Equation

Correlation analysis is a statistical technique used to assess the strength and closeness of the relationship between two variables. It relies on the correlation coefficient, which expresses this relationship numerically. Analysis assumes a linear association between the quantitative variables (Gogtay & Thatte, 2017). The correlation coefficient ranges from -1.0 to +1.0, with values closer to 1 indicating a stronger correlation. The sign of the coefficient indicates the direction of the relationship, whether positive or negative. The interpretation of the correlation coefficient is as follows (see figure 2).

The correlation value was obtained by using the following formula:

$$r = \frac{n \times (\sum(X.Y) - (\sum(X) \times \sum(Y)))}{\sqrt{(n \times \sum(X^2) - (\sum(X)^2)} \times \sqrt{n \times \sum(Y^2) - (\sum(Y)^2)}} \ldots (5)$$

where:
r : Correlation coefficient value
Σ(X) : Total observation variable X
Σ(Y) : Total observations variable Y
Σ(X.Y) : Total product of the variables X and Y
$\Sigma(X^2)$: Total square of the observed variable X
$\Sigma(X)^2$: Total squared of the total observations of variable X
$\Sigma(Y^2)$: Total square of the observed variable Y
$\Sigma(Y)^2$: Total squared of total observations variable Y
n : Total pairs of observations Y and X

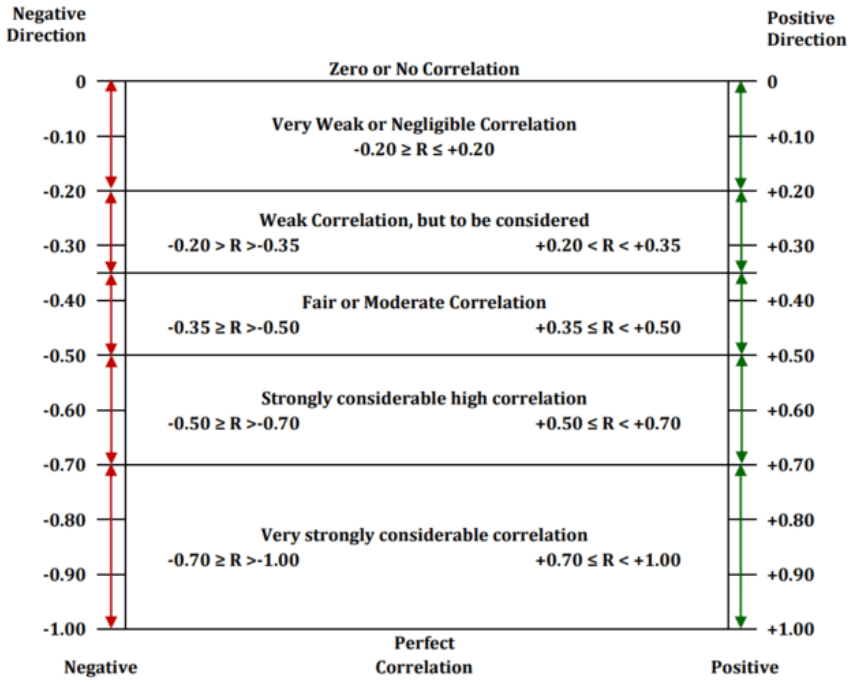


Figure 2. Correlation coefficient value between two variables (Senthilnathan, 2019)

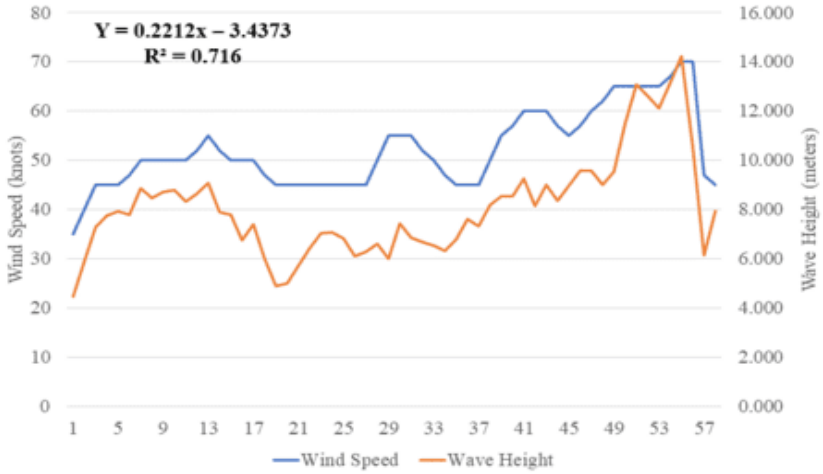


Figure 3. Wind speed and wave height along Cyclone Seroja path.

2.5. Equation of Fast Propagation of Sea Wave

Wave propagation formula refers to calculating the distance traveled by wave within a specific time unit. Similar to the concept of speed, fast wave propagation is characterized by its swift movement. In this context, it is common to use a vector quantity that represents a constant velocity to describe the rapid propagation of wave.

The speed of wave propagation was calculated using the formula (Serway & Jewett, 2008):

$$V = \frac{S}{t} \quad \ldots\ldots\ldots(6)$$

where:

v = speed of wave propagation (km/hour)
s = distance between the tidal and wave stations (km)
t = time difference between the peak wave height at wave station and the residual peak at the tidal station (hours).

3. Result and Discussion

The obtained results specifically analyze influence of Seroja tropical cyclone on wave height and tide.

3.1. Influence of Cyclone Seroja on Wave Height

The Indian Ocean and the western waters of Australia have been identified as highly conducive areas for tropical cyclone growth. Although Indonesian waters generally remain consistent throughout the year, the development of tropical cyclone in this territory can trigger the formation of high wave (Habibie & Fitria, 2019).

According to the data shown in Table 1, it is evident that Cyclone Seroja experienced varying levels of intensity during the observed period. On April 4, 2021, at 12:00 UTC, the minimum wind speed recorded was 35 knots, accompanied by wave height of 4.46 meters. However, on April 11, 2021, at 06:00 UTC, the maximum wind speed reached 70 knots, with a corresponding maximum wave height of 14.24 meters. The findings highlight the significant intensity and impact of Cyclone Seroja during that time. These are consistent with the research conducted by (Liufandy *et al*., 2022), which emphasized the influential role of wind in driving wave height and the generation of powerful, energy-laden wave.

Based on Figure 3, the greater the wind speed increases, the higher the formation of sea wave. In order to determine the strength of the relationship between wind speed and height, both regression and correlation tests were performed. The regression analysis results revealed an R^2 value of 0.716, indicating that approximately 71.6% of the variability in wave height can be explained by changes in wind speed (Kurniawan & Budi, 2016). Furthermore, the correlation calculation demonstrated a strong relationship between wind speed and height, with a correlation coefficient of 0.846, specifically during Cyclone Seroja (Senthilnathan, 2019).

The findings prove the significant relationship between wind speed and height, consistent with previous research (Ilia & O'Donnell, 2018), where ocean waves are generated due to generating forces acting on the ocean, one of which is wind. Wind from storms can significantly increase wave height and can be a strong generating force for ocean waves. As a result, the ocean waves formed tend to have higher heights and greater energy.

Table 1. Wind speed and height on Cyclone Seroja track.

No	Coordinate		Time (UTC)	Wind Speed (knots)	Wave Height (meters)
	Longitude	Latitude			
1.	123.20	-10.40	4/4/2021 12:00	35	4.460
2.	120.00	-11.40	4/6/2021 0:00	55	9.083
3.	119.70	-11.60	6:00	50	7.797
4.	119.30	-11.90	12:00	50	7.395
5.	118.00	-13.30	4/7/2021 0:00	45	5.713
6.	116.80	-14.20	6:00	45	7.025
7.	115.60	-15.10	12:00	45	6.819
8.	112.50	-16.30	4/8/2021 0:00	55	6.001
9.	111.90	-17.10	6:00	55	6.849
10.	111.50	-17.50	12:00	50	6.531
11.	110.10	-19.00	4/9/2021 0:00	45	7.335
12.	109.50	-19.60	6:00	55	8.530
13.	108.90	-20.00	12:00	60	9.271
14.	108.20	-20.60	4/10/2021 0:00	55	8.964
15.	108.20	-20.90	6:00	60	9.571
16.	108.80	-21.60	12:00	65	9.539
17.	110.50	-24.20	4/11/2021 0:00	65	12.122
18.	112.00	-26.10	6:00	70	14.240

(Source: IBTrACS and *Marine Copernicus*)

3.2. Influence of Cyclone Seroja on Tide

In this sub-chapter, the focus shifts towards investigating the effects of Cyclone Seroja on tidal patterns in two specific regions, namely Cape Cuvier and Kupang in Australia and Indonesia, respectively.

3.2.1. Cape Cuvier Australia

Wave height data from stations 669, 870, 1070, 1279, 1445, 1487, and 1325 were collected along the path of Cyclone Seroja, as shown in Figure 4. The tidal data used in analysis was obtained specifically from the Cape Cuvier tide station in Australia.

Based on analysis shown in Figure 5, it was found that station 1325, located closest to the Cape Cuvier tidal station, played a significant role in capturing wave data. In order to determine the direction of wave propagation towards station 1325, wave rose analysis was conducted. The results revealed that the dominant wave direction observed between April 3 and 13, 2021, ranged from 209 to 211 degrees. This wave exhibited height ranging from 3.60 meters to 5.70 meters, occurring approximately 60 times the total 232 data points analyzed. It is worth noting that the predominant wave direction originated from wave station 1487, as shown in Figure 4 and Figure 5.

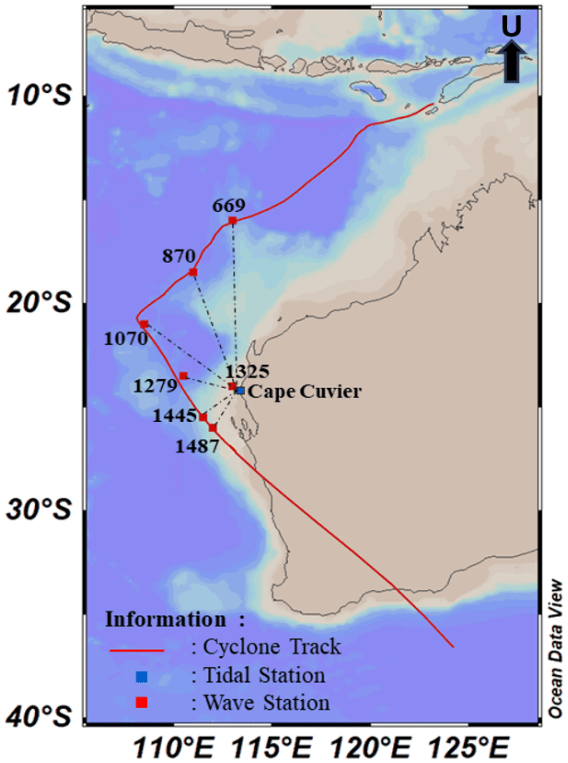


Figure 4. Sketch of the path of Cyclone Seroja, wave stations, and the Cape Cuvier tidal station

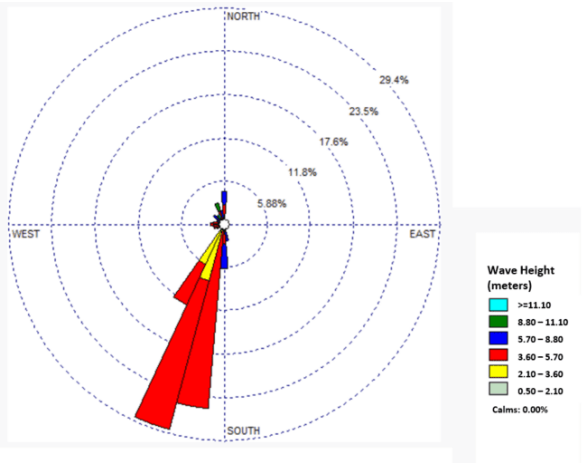
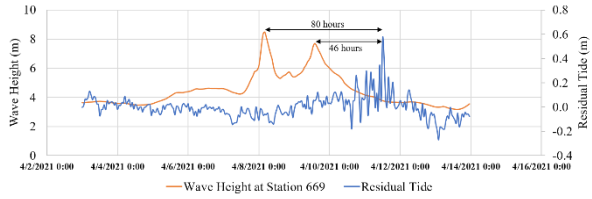


Figure 5. Wave rose wave data at station 1325

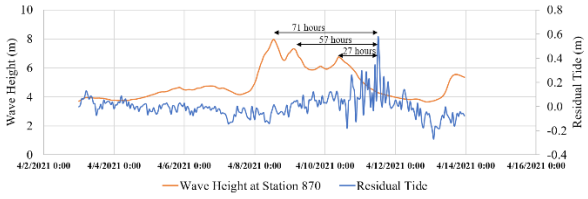
Considering the data shown in Figure 6, wave station 669 recorded two notable peak wave events. The first peak, labeled as 669(1), occurred on April 8, 2021, at 04:00 UTC, with height of 8.488 meters. In addition, it was observed 80 hours after the residual peak. The second peak, labeled as 669(2), took place on April 9, 2021, at 14:00 UTC, with height of 7.710 meters. It occurred 46 hours after the residual peak. Wave station 669 is located at a distance of 921.4 km from the Cape Cuvier tide station.

Wave station 870, located 680.5 km from the Cape Cuvier tidal station, experienced three significant peaks in wave height. The first peak, labeled as 870(1), occurred on April 8, 2021, at 13:00 UTC, with height of 7,975 meters. Besides, it occurred 71 hours after the residual peak. The second peak, labeled as 870(2), took place on April 9, 2021, at 03:00 UTC, with height of 7,316 meters, and was observed 57 hours after the residual peak. The third peak, labeled as 870(3), was recorded on April 10, 2021, at 09:00 UTC, with height of 6,762 meters, and it occurred 27 hours after the residual peak.

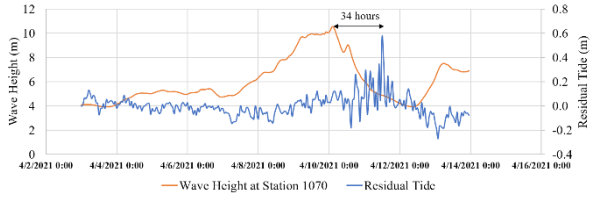
Meanwhile, wave station 1070, located 617.6 km from the Cape Cuvier tidal station, experienced a peak wave height on April 10, 2021, at 02:00 UTC. Height of the peak was 10.519 meters, and it occurred 34 hours after the



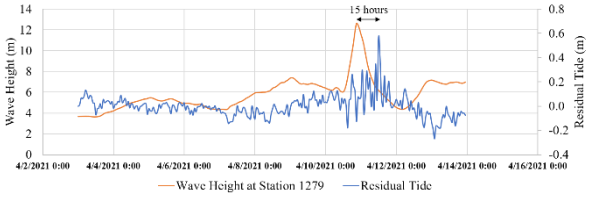
(a) Station 669



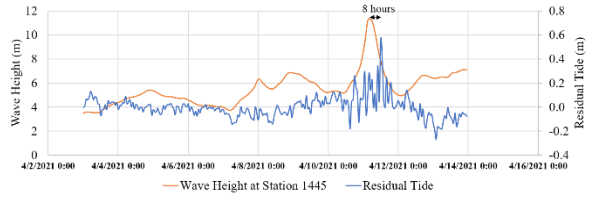
(b) Station 870



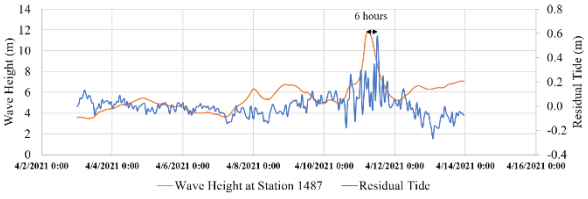
(c) Station 1070



(d) Station 1279



(e) Station 1445



(f) Station 1487

Figure 6. Wave height in the path of Cyclone Seroja and the residual height of tide at the Cape Cuvier tidal station.

Table 2. The sequence of occurrence of extreme wave crests

Wave Station (peak wave)	Time at MaxH (UTC)	MaxH (m)	Time Difference (hours)	Distance to Tidal Station (km)	Wave Propagation Velocity (km/hours)
1445	4/11/2021 4:00	11.333	8	238.265	29.78
1487	4/11/2021 6:00	11.790	6	242.516	40.42

residual peak. Wave station 1279, situated 306.7 km from the Cape Cuvier tidal station, recorded a peak wave height on April 10, 2021, at 21:00 UTC. Height of this peak was 12.619 meters, with a time difference of 15 hours from the residual peak. Wave station 1445, located 238.3 km from the Cape Cuvier tidal station, documented a peak wave height on April 11, 2021, at 04:00 UTC, measuring 11.3 meters. The time difference between this peak and the residual was 8 hours. Lastly, wave station 1487, situated 242.5 km from the Cape Cuvier tidal station, experienced a peak wave height on April 11, 2021, at 06:00 UTC, reaching 11.79 meters. The time difference between this peak and the residual was 6 hours. This information is also shown in Table 2.

There was a significant change in the residual value at the Cape Cuvier tidal station on April 11, 2021, at 12:00 UTC, with height reaching 0.57 meters. This notable change is likely attributable to the arrival of tidal wave in the area. Coincidentally, wave stations 1445 and 1487 experienced peak wave height on the same day. In order to determine whether these wave stations influenced the significant change in the residual value at the Cape Cuvier station, it is necessary to consider wave propagation speeds. The calculated wave propagation speeds are shown in Table 2, providing valuable insights into the potential link between wave stations and the observed shift in the tidal patterns at Cape Cuvier.

According to the data shown in Table 2, wave station 1487, which is located 242.5 km from the Cape Cuvier tidal station, exhibits the highest wave propagation speed towards the tidal station, recorded at 40.42 km/h over a 6-hour time range. This indicates that wave station 1487 has a dominant influence on wave height observed at the Cape Cuvier tidal station. The research findings revealed a significant impact of wave height propagation from station 1487, leading to a notable increase in the residual water level at the Cape Cuvier tidal station, with a recorded height of 0.52 meters.

Previous research conducted by Ningsih et al. (2020) has consistently shown that tropical cyclone significantly impact raising the residual water level in coastal areas. This is further supported by (McInnes et al., 2016), who stated that wave height caused by tropical cyclone propagate toward the coast. As this wave approaches the shore, they attenuate or break, ultimately causing a substantial increase in tidal and flood levels.

3.2.2. Kupang Indonesia

Data was acquired from the Kupang tide station while specifically focusing on tide data. In addition, wave data was acquired from multiple wave stations located near the Kupang tide station. These include stations 197, 198, 237, 238, 239, and 240, as shown in Figure 7.

According to the data shown in Figure 8, peak wave height was observed at various wave stations during specific times. On April 4, 2021, at 21:00 UTC, wave station 197 recorded the highest wave height of 9.32 meters. At the same time, wave station 198 experienced a peak wave height of 8.22 meters. On April 5, 2021, at 07:00 UTC, wave station 237 reached its highest recorded wave height of 10.41 meters, while

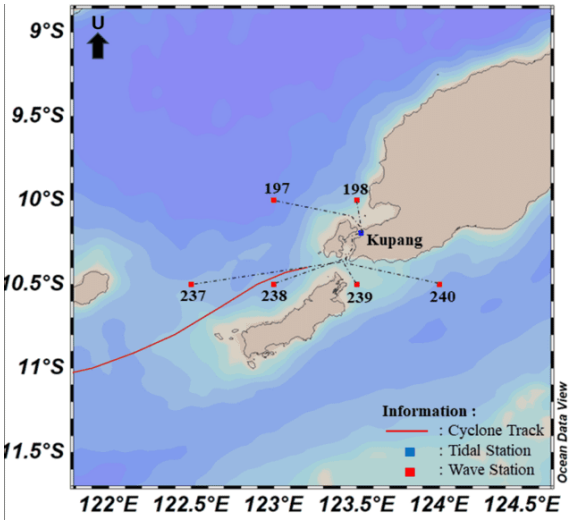


Figure 7. Sketch of Cyclone Seroja track, wave stations, and Kupang tidal station

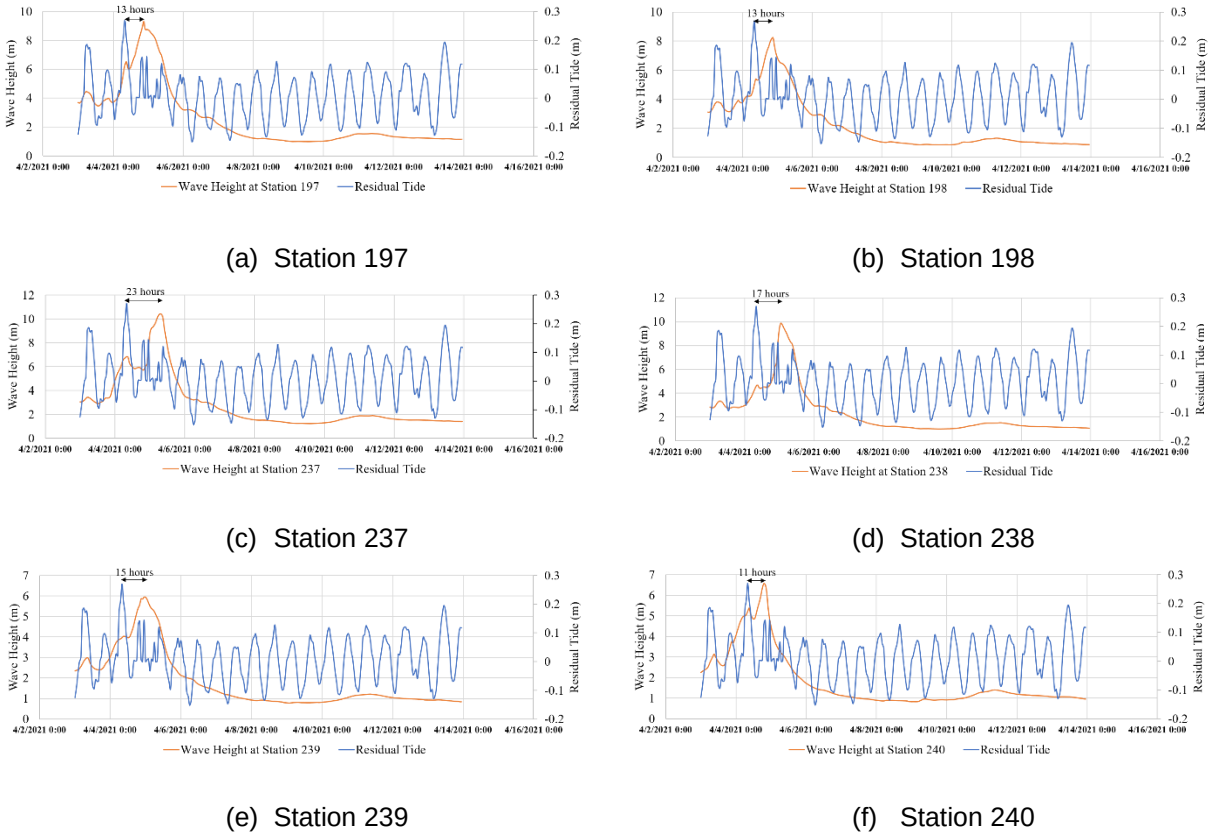


Figure 8. Station wave height 197, 198, 237, 238, 239, 240, and the residual height of tide at the Kupang tidal station. The distribution of stations can be seen in Figure 7

wave station 238 recorded its peak wave height of 9.85 meters at 01:00 UTC on the same day. Wave station 239 registered a peak wave height of 5.96 meters on April 4, 2021, at 23:00 UTC, and wave station 240 observed its highest wave height of 6.56 meters on the same day, at 08:00 UTC.

Furthermore, on April 4, 2021, at 08:00 UTC, the Kupang tidal station recorded the highest residual height of 0.27 meters. It is worth noting that this residual height occurred prior to the peak wave observed at the nearby wave stations. These findings differ slightly from the research conducted by (Ningsih et al., 2020), as it implies that the peak wave do not directly influence the highest residual height during the mature phase of Cyclone Seroja. This incident occurred from April 4, 2021, at 09:00 UTC to April 11, 2021, at 15:00 UTC.

Based on the data, there is a possibility that the highest residual height recorded at the Kupang tidal station can be attributed to wave height during the formation stage of cyclone. These findings suggest that the impact of wave height on the residual water level may be more pronounced during the early stages of cyclone development rather than the mature phase.

During the formation phase of Cyclone Seroja, there was a distribution of low-pressure events occurring from April 1, 2021, at 23:00 UTC to April 4, 2021, at 01:00 UTC. The research specifically focused on examining the low-

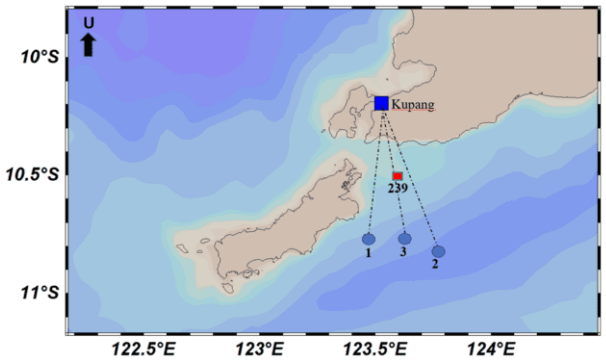


Figure 9. Sketch of low pressure, Kupang tidal station, and wave 239 station

Table 3. Low pressure around the 239-wave station at the stage of the formation of Seroja tropical cyclone

No	Time (UTC)	Coordinate		Pressure (hPa)	Wave Height at Station 239 (m)
		Long	Lat		
1.	4/4/2021 4:00	123.47	-10.77	999	3.73
2.	4/4/2021 7:00	123.77	-10.82	1002	3.91
3.	4/4/2021 10:00	123.63	-10.77	1001	4.02
Average				1001	3.89

pressure events that coincided with the peak residual tide in Kupang on April 4, 2021, at 08:00 UTC, as well as wave height recorded at the closest wave station.

Figure 9 shows that during the peak of the residual tide in Kupang, the adjacent low-pressure events were numbered 1, 2, and 3. These low-pressure events are observed to occur at times that closely coincide with the peak tide in Kupang. Furthermore, Table 3 shows that wave station 239 is the relevant one associated with this analysis.

According to the data in Table 3, on April 4, 2021, at 04:00 UTC, the air pressure around wave station 239 was recorded as 999 hPa, with a corresponding wave height of 3.73 meters. By 07:00 UTC, it had risen to 1002 hPa, accompanied by wave height of 3.91 meters. However, at 10:00 UTC, the air pressure decreased to 1001 hPa, while wave height increased to 4.02 meters. The average values calculated indicate that the low pressure around wave station 239 had an average pressure and wave height of 1001 hPa and 3.89 meters, respectively. These findings suggest that the peak residual tide in Kupang was influenced by the low pressure observed around wave station 239, characterized by an average pressure and wave height of 1001 hPa and 3.89 meters, respectively. Furthermore, these factors propagated towards the Kupang tidal station during the formation phase of Tropical Cyclone Seroja.

This research is consistent with Kurniawan *et al*. (2021), which confirms the existence of a tropical cyclone seed with the code 99S. This cyclone was identified on April 1, 2021, at 23:00 UTC in the Sawu Sea, East Nusa Tenggara, precisely located at coordinates 9.6°S 121.8°E. At its inception, the cyclone exhibited an air pressure of 1004 hPa and a wind speed of 25 knots. The growth phase of this cyclone lasted approximately three days, from April 2 to 4, 2021. Moreover, the research findings are further supported by Ningsih *et al*. (2020), who reported the negative correlation between the atmospheric pressure at the center of cyclone and the subsequent increase in residual water height in Indonesian waters

4. Conclusions

In conclusion, the occurrence of Cyclone Seroja, on April 11, 2021, at 06:00 UTC, recorded a maximum wind speed and wave height of 70 knots and 14.24 meters, respectively. The regression statistical test results yielded an R2 value of 0.716, indicating that approximately 71.6% of the variation in wave height can be explained by changes in wind speed. Additionally, the correlation calculation revealed a strong relationship between wind speed and wave height, with a value of 0.846. This emphasizes the significant influence of wind speed on wave height during cyclone events.

Wave station 1487 demonstrated the highest wave propagation speed towards Cape Cuvier tidal station, measured at 40.42 km/h. This specific wave station significantly influences the tidal station, indicating that wave height propagated from wave station 1487 substantially impacts the significant residual height observed at Cape Cuvier tidal station.

The Kupang tidal station recorded its highest residual height of 0.27 meters on April 4, 2021, at 08:00 UTC. This measurement suggested that the peak wave during Cyclone Seroja did not influence this particular maximum residual height.

The peak of the residual tidal surge in Kupang resulted from the influence of low pressure around wave station 239. This particular station had an average pressure and wave height of 1001 hPa and 3.89 meters, respectively. These factors propagated towards the Kupang tidal station during the formation phase of Tropical Cyclone Seroja.

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