International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

Vol. 42 No. 2 January 2024, pp. 497-506

Wind, Wave And Ocean Current Characteristics To Support Maritime Security In The Malacca Strait

Arditho Bramandika Putra[1,2], Mauliza Fatwa Yusdian[1], Ajiz Nur Efendi[1,2], Trismadi[1], AndrianAndaya Lestari[1], AgusHaryanto Ikhsanudin[1]

[1] Department of Defence Science and Technology, Indonesia Defence University, Sentul 16810
[2] Meteorology, Climatology, and Geophysics Agency of Indonesia, Jakarta 29125
E-mail: arditho.putra@bmkg.go.id

Abstract— The Strait of Malacca, located between Malaysia and Indonesia, is a strategic and economic shipping lane on parwith the Suez Canal and the Panama Canal. Its existence has a significant impact especially in the economic and military context in the Asia-Pacific. Maritime security in the Malacca Strait is a major focus, covering aspects ofnavigation, countering transnational crime, and addressing non-traditional issues such as environmental security and search and rescue operations at sea. This research uses data processing methods and oceanographic meteorological modelling systems by utilising multidimensional data in NetCDF format, developed by BMKG. The results show that the wind in the Malacca Strait generally blows from the Northwest and Southeast with an average speed of 0-6 knots, reaching a maximum of 20-30 knots especially in the central and northern parts of the Malacca Strait. The average wave height is 0.0-0.5 metres, with maximum heights reaching 3-5 metres. Currents have an average speed of 0-30 cm/s, with maximum speeds reaching 60-100 cm/s. Thus, in terms of Shipping Safety, conditions in the Malacca Strait can be considered relatively safe. However, it is necessary to be aware of changes in weather conditions that may occur suddenly, especially during transitional or transitional periods. This study makes an important contribution to the understanding of maritime security in the Malacca Strait, enabling relevant parties to take the necessary measures to ensure the safety and security of shipping inthe region.

Keywords: Malacca Strait, Shipping, Maritime Security, Economy, Safety

I. INTRODUCTION

The Malacca Strait, located between Malaysia and Indonesia, is one of the busiest straits inthe world (Rusli et al., 2021). From an economic and strategic perspective, the Malacca Strait is one of the most important shipping lanes in the world, as important as the Suez Canal or the Panama Canal (Wan et al., 2021). The existence of the Malacca Strait as one of the most important trade routes in the world cannot be separated fr om various interests. In terms of economic and military interests, the Malacca Strait is avery strategic bottleneck for the naval fleets of Asia-Pacific countries. This situation makes all countries dependent on maritime security in the Malacca Strait. Maritime security has become an important issue that attracts the attention of the entire world community in this modern era. The concept of maritime security addresses a variety of issues, particularly safety of navigation, the suppression of transnational crimes such as sea piracy and maritime terrorism, as well as conflict prevention and resolution (Sandkamp et al., 2022). In addition, in the context of non-traditional security, issues such as maritime environmental security and search and rescue operations at sea become very important (Wu, 2016).

Shipping safety is also included in maritime security, which depends on the weather at sea. Weather parameters that affect shipping safety at sea include wind, waves, and ocean currents. Windis an energy caused by temperature changes between cold air and hot air (Kadir, 1995). The wind blows from a high pressure area to a low pressure area. Sea waves are a vertical mechanism of the riseand fall of the sea surface that occurs instantly until it reaches equilibrium (Purba & Pranowo, 2015) while ocean currents are horizontal movements of water masses that can be caused by various things including wind on the sea surface, density differences and the influence of ocean tides (Hadi and Radjawane, 2009). Before carrying out activities at sea, usually the ship's crew will seek information about weather conditions during the journey. Weather information in Indonesia is issued by the Meteorological, Climatological and Geophysical Agency asa government agency whose main task is to provide weather information to the public. The weather information is processed using a model with several input elements that affect it.

By focusing on an in-depth understanding of marine weather characteristics such as wind, waves and currents in the Malacca Strait, this research is expected to make a significant contributionto the development of shipping safety and maritime security policies. The results of this study are expected to provide valuable guidance to maritime authorities, shipping companies and other stakeholders in implementing preventive and risk mitigation measures. As such, these measures will not only improve the safety of shipping operations in the Malacca Strait but also protect the maritime environment as a whole.

II. RESEARCH METHODS

2.1 Research Location

This research focussed on a specific area of the Malacca Strait, which is a strategic shipping lane connecting the Indian Ocean with the South China Sea. The research site covers a number of geographical coordinates along the Malacca Strait, involving the waters between Sumatra Island (Indonesia) and Peninsular Malaysia.

Figure 1: Map of the Malacca Strait RegionSource:Geospatial Information Agency (BIG)

2.2 Data Processing

The data in this research is processed using a High Performance Computer (HPC) on the BMKG server using the Python programming language, among others:

a. NetCDF format Multidimensional Data

Multidimensional data is data that has more than 2 dimensions. Weather parameter data suchas air temperature data arranged spatially based on latitude and longitude in a certain time span can be called multidimensional data. Suppose we have data on a certain area in theform of a grid (boxes) and we arrange it like sheets on a stack of paper arranged in a landscape, then the length, width, and thickness of the stack of paper are called dimensions. In the stack of paper, the length of the paper can be called the longitude/longitude dimension, the width of the paper can be called the dimension of latitude/latitude, while paper thickness can be referred to as the time dimension (Henderson & Vellidis,2016; de Jong, Kooi, & Koper, 2012). An illustration of the NetCDF data formis shown in the following figure:

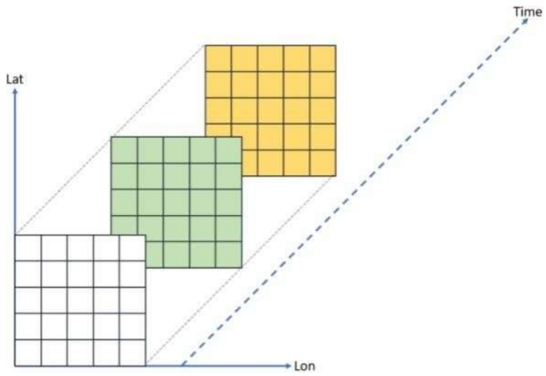

Figure 2. NetCDF data illustration shape

b. Basic components of NetCDF data

The basic components of a NetCDF file are Dimensions, Variables, Coordinate variables, and Attributes. Thesecomponents help us understand the data contained in a NetCDF file and the relationship between data fields in a data set. The following will briefly explain the basic components of a NetCDF file:

a) Dimensions

Dimensions on NetCDF files serve to identify and categorise data values based on specific axes. Dimensions onNetCDF files represent the original physical dimensions such as latitude, longitude, depth, time etc.

b) Variables

A variable is a collection of a set of data on a particular parameter (e.g. wind, air temperature, etc.). A variable has a name, data type, and the shape/order of its dimensions.

c) Cordinate Variables

Coordinate variables represent values of a particular dimension, such as degrees of latitude, degrees of longitude, and a particular time. Coordinate variables have only onedimension, which is the represented dimension itself.

d) Attributes

Attributes in NetCDF files store metadata information on the file or on variables within the file itself. Attributes contain information about variable names, units, etc. Attributesthat contain information about the entire document are called global attributes. (Unidata, 2020; NASA, 2020)

c. BMKG OFS (Ocean Forecasting System) operation

BMKG Ocean Forecast System is an osceneographic meteorological modelling systemdeveloped by BMKG since 2015 and inaugurated in 2017. BMKG OFS is intended to support better maritime meteorological information services. BMKG OFS was developed to fulfil the needs of wave, current, salinity and sea temperature information analysis and forecasting. BMKG OFS consists of two main components, namely the Ocean Wave Model known as Ina-Waves to support wave information, the Ocean Circulation Model known as Ina-Flows to support information on currents, salinity and sea temperature at any depth. The third is the Drift and Coastal Model to support information on object trajectory, oil spill and sea level.

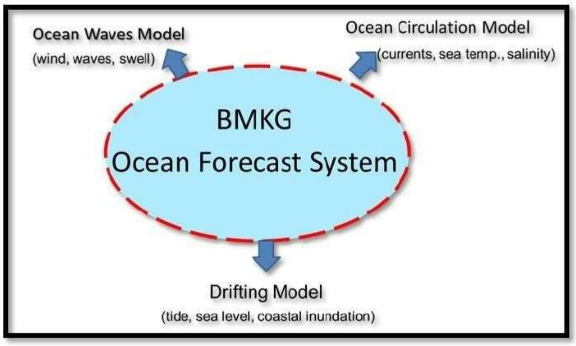

Figure 3. BMKG OFS Schema

Ina-Waves is a third generation spectral wave model (Wavewatch III), and is then coupled with a shallow or nearshore ocean wave model (Simulated WAves Nearshore - SWAN) using the nesting method. The Ina-Waves modelhas 3 (three) domains which are then used asboundary values for the following domains, while the forcing used at this time is NOAA GFS with a resolution of 0.5° and WRF 10 km. Ina-Waves outputs Wave Height, Wave Direction, Wave Period, Swell Direction, and Wind Speed and Direction. Ina-Flows is a Finite Volume Community Ocean Model (FVCOM), a computational fluid dynamics software applied to geophysical flows in coastal areas (Chen et al., 2003). The model can be applied for simulation processes in coastal areas including estuaries, shelf break fronts and tidal mixing zone fronts. Ina-Flows takes into account wind, tidal, and external weather forces to calculate current speed and direction. Ina-Waves and Ina-Flows run a 12-hourly forecast run, which outputs a 12-hourly NetCDF file. The netcdf file contains 10-day (Ina-Waves) and 7-day (flows) forecasts. The results of running the Ina-Waves and Ina-Flows models produce output in the form of NetCDF files (Marelsa & Oktaviandra, 2019)(Anggara et al., 2022)(Sinaga & Luthfia, 2019).

d. Data Analysis

The analysis data accessed in this study consists of the first time step of each NetCDF file generated from running the Ina-Waves and Ina-Flows models. It is important to note that thecharacteristics of these data are categorisedas "analysis data" due to their nature as model inputs, which are essentially used to generate forecasts in the context ofthis study. These data include fundamental information used by the Ina-Waves and Ina-Flows models to reconstruct atmospheric and oceanographic conditions in the Malacca Strait region. In other words, this analysis data provides an initial and representative picture at the first time step inthe observation period considered. The success of the model in providing accurate forecasts depends on the accuracy and relevance of the analytical data used as the basis for the calculations. The choice of the first time step as the focus of the analysis also implies that this data has a significant impact on the initialisation of the model, providing the basis forthe forecasts generated during subsequent times. Therefore, an in-depth understanding of thequality and characteristics of the analysis data is crucial in evaluating model performanceand interpreting the forecasting results generated from the Ina-Waves and Ina-Flows models.Further analysis of these data will provide greater insight into the accuracy and reliability of the models, which is essential in understanding the atmospheric and oceanographic dynamics of the Malacca Strait and its implementation in long-termforecasting scenarios.

e. Climatological Data Processing

The procedure used in the acquisition of climatological data is illustrated through a flow chart that has been arranged in a systematic and structured manner. The flowchart is a visualrepresentation of a series of steps taken in theprocess of collecting, processing and analysing climatological data, with the ultimate aim of gain a deeper understanding of the meteorological and oceanographic conditions in the Malacca Strait region. The procedure for obtaining climatological data is shown in the following flow chart:

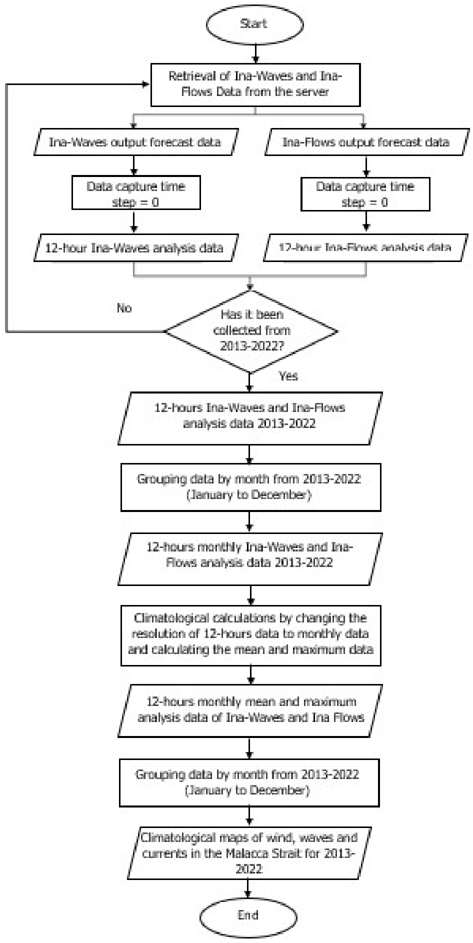

Figure 4. Climatological Data Processing Flow Chart

Firstly, the 12-hour NetCDF data from the Ina-Waves and Ina-Flows models were taken andextracted at time step = 0 for a span of 10 years (2013 - 2022). This was done to take 12- hourly analysis data for 10 years. Next, the 12-hourly analysis data for 10 years was groupedby month, from January to December. After the data is grouped, the monthly average is calculated to produce monthly climatological data for 2013 - 2022. After averaging per month and obtaining monthly climatological data for 2013-2022, the last step is toplot using Python. The final product produced is the Climatological Map of Currents, Winds, and Waves in Indonesia 2013 - 2022. An example of a climatological data processing script using Python is shown in the following figure:

```python
#Mengelompokkan per bulan
months = ds2plot_wv.groupby('time.month').groups
y1, y2 = ds2plot_wv.time[0].dt.strftime("%Y").data, ds2plot_wv.time[-1].dt.strftime("%Y").data
out_dir = f'./{nama_folder}/Wind/{map_area}/{y1}_{y2}'
if not os.path.exists(out_dir):
    os.makedirs(out_dir)

for month in months:
    month_name = calendar.month_name[month]
    print(f"Menghitung parameter klimatologis untuk bulan {month_name}")

    # Calculate wind parameter
    uwnd_mean = ds2plot_wv.uwnd.isel(time=months[month]).mean(dim='time').compute()
    vwnd_mean = ds2plot_wv.vwnd.isel(time=months[month]).mean(dim='time').compute()
    wind_mag = np.sqrt(np.square(uwnd_mean) + np.square(vwnd_mean))
    wind_u = 2. * uwnd_mean / wind_mag
    wind_v = 2. * vwnd_mean / wind_mag

    print("\tMembuat peta")
    lat = ds2plot_wv.lat.values
    lon = ds2plot_wv.lon.values


    wsd_avg_title = f'Monthly Average Wind Speed and Direction {month_name} {y1}-{y2}'


    fl_out_wsdavg = f"{out_dir}/WSD_AVG_Climatology_{map_area}_{y1}_{y2}_{'%.2d' % month}"
```

Figure 5. Climatological Data Processing Script

2.3 Data Analysis Method

The method for data analysis in this study uses a descriptive method by describing theresults of data processingin the form of spatial maps of wind, waves, and ocean currents. The data analysis method applied in this research is the descriptive method, which in detail describes and outlines the results obtained through the data processing process. The use of this descriptive method focuses on presenting information in a systematic and structured manner, with the aim of clearly describing the spatial characteristics of certain climatological variables in the Malacca Strait region. The analysis process involves transforming the climatological data collected over a ten-year period into spatial maps that include the spatial distribution of winds, waves and ocean currents. The use of spatial maps as a visualisation tool allows researchers to observe and analyse spatial patterns that may appear in the data. Each climatological variable, such as wind direction and speed, wave height and ocean current speed, is mapped in detail to provide a comprehensive picture of the meteorological andoceanographic dynamics in the Malacca Strait. By applying this descriptive method, the research not only presents the numerical results of data processing, but also opens up space for deeper interpretation related to the phenomena contained in the climatological data. This method provides a strong basis for developing a rich and comprehensive scientific narrative, contributing significantly to a deeper understanding of the climatic and oceanographic conditions in the Malacca Strait region.

III. RESULT AND DISCUSSION

Based on the analysis of climatological data processed over a period of ten consecutiveyears in the Malacca Strait region, a number of significant findings were obtained that can provide an in-depth understanding of the climatic and meteorological conditions in the area. The data covers a wide range of climatological parameters, including wind direction and speed, wave height and ocean current speed. The research is based on information systematically collected over the past decade,providing a comprehensive picture of the climate patterns and meteorological phenomena affectingthe Malacca Strait.

3.1 Wind Data (10 Years of Climatological Data in the Malacca Strait)

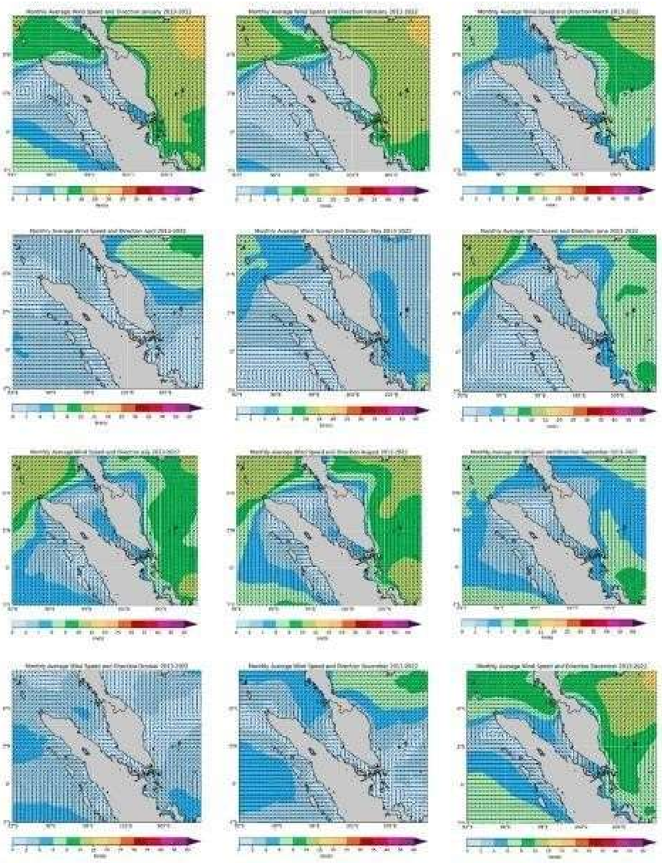

Figure 6. Average Wind Climatological Data for 10 Years in The Malacca Strait

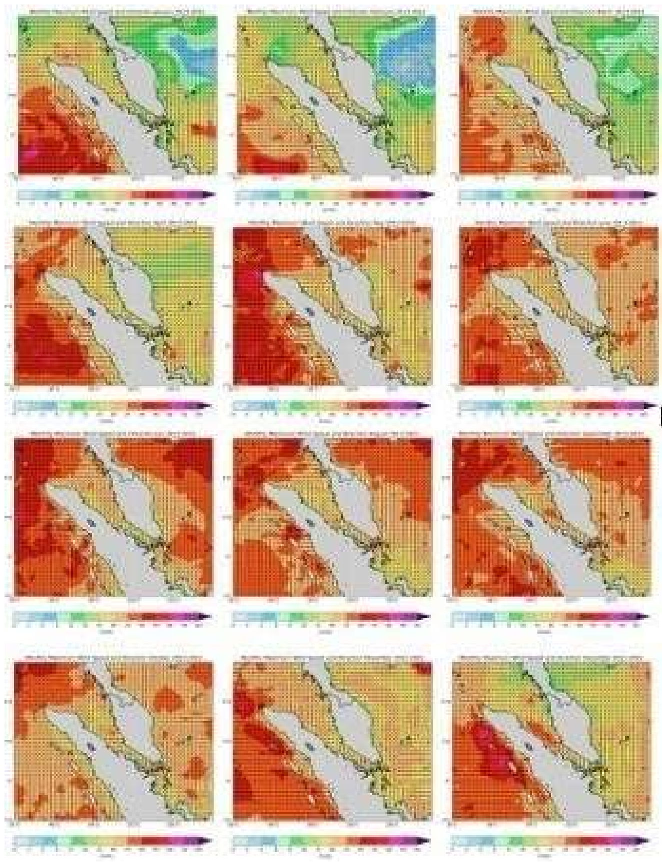

Figure 7. Maximum Wind Climatological Data for 10 Years in The Malacca Strait

The analysis of climatological data related to wind speed, as depicted in Figures 6 and 7, provides a comprehensive picture of the atmospheric dynamics in the Malacca Strait over a ten-year period. The main focus of the analysis is on the average and maximum wind speeds, which provide a deep insight into their potential influence on maritime activities in the region. From the observations, the average wind speed over the decade showed relatively limited variation, ranging from 0 to 6 knots. Interestingly, there is a dominant pattern in wind direction during certain months. At the beginning of the year, especially from January to March, the wind direction tends to be dominantly from the Northwest. However, as the year progresses, there is a significant change in pattern, where the wind direction begins to shift from Northwest in the early months to Southeast in the middle of the year,and back again from Southeast to Northwest at the end of the year. Average wind speeds that were generally stable and within a range favourable to maritime activities were a positive point from this analysis. However, it should be noted that caution is needed especially on the maximum wind speeds recorded, especially from July to December. During this period, maximum wind speeds can reach 20 to 30 knots (36 to 54 km/h), especially in the central and northern Malacca Strait areas. Emphasis on the variability of wind direction and maximum wind speed provides further understanding of the potential challenges and risks that may be faced in maritime activities in the Malacca Strait. Therefore, this information has significant implications in the context of shipping security and maritime safety in the region, and can form the basis for the development of more effective risk mitigation strategies.

3.2 Wave Data (10 Years of Climatological Data in the Malacca Strait)

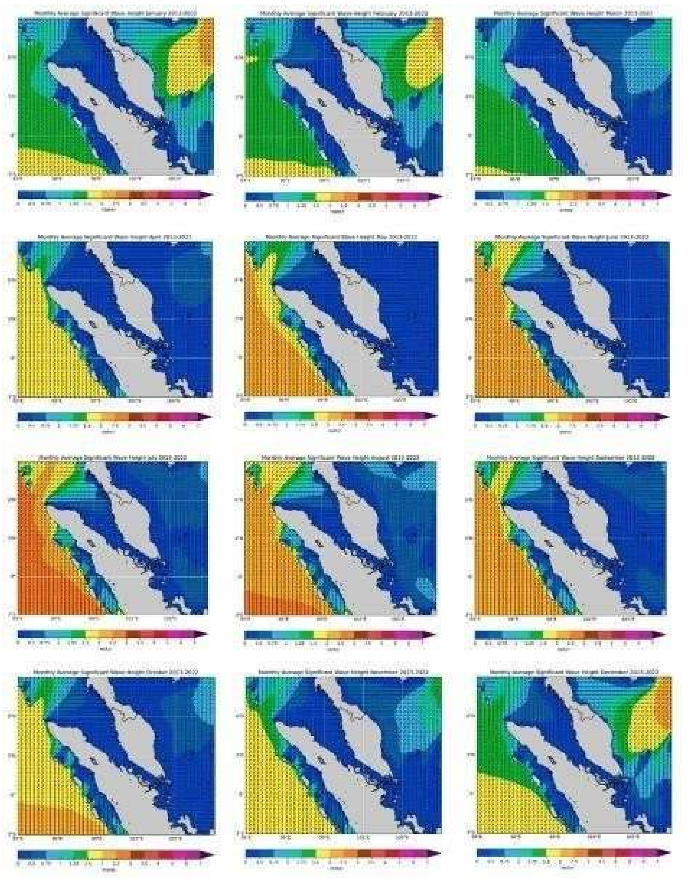

Figure 8. Average Wave Climatological Data for 10 Years in The Malacca Strait

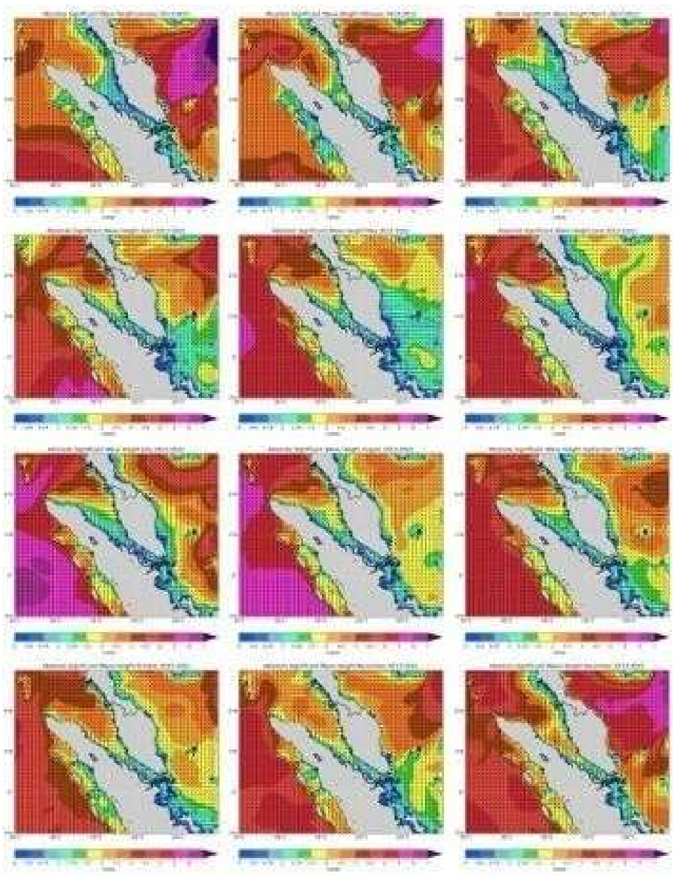

Figure 9. Maximum Wave Climatological Data for 10 Years in The Malacca Strait

From the data processing results documented in Figures 8 and 9, it can be seen that there are significant variations in the climatological data related to wave heights in the Malacca Strait over a period of ten years. The analysis revealed that the average wave height over the decade ranged from 0 to 0.5 metres, with the dominant direction of wave propagation towards theSoutheast. Interestingly, from April to October, there is an increase in wave heights, particularly in the northern Malacca Strait. During this period, wave heights reach 0.5 to 1.5 metres. While the ten-year average wave height can support maritime activities in the Malacca Strait, it should be noted that the maximum wave heightthat can occur is 3 to 5 metres. This analysis provides a deep insight into the wave dynamics in the Malacca Strait, and highlights the potential risks associated with high maximum wave heights. In the context of maritime security, this understanding is critical, as significant wave heights can jeopardise the safety of various marine activities. Therefore, this expanded knowledge can assist in the development of more effective risk mitigation strategies and safety policies in the Malacca Strait region.

3.3 Current Data (10 Years of Climatological Data in the Malacca Strait)

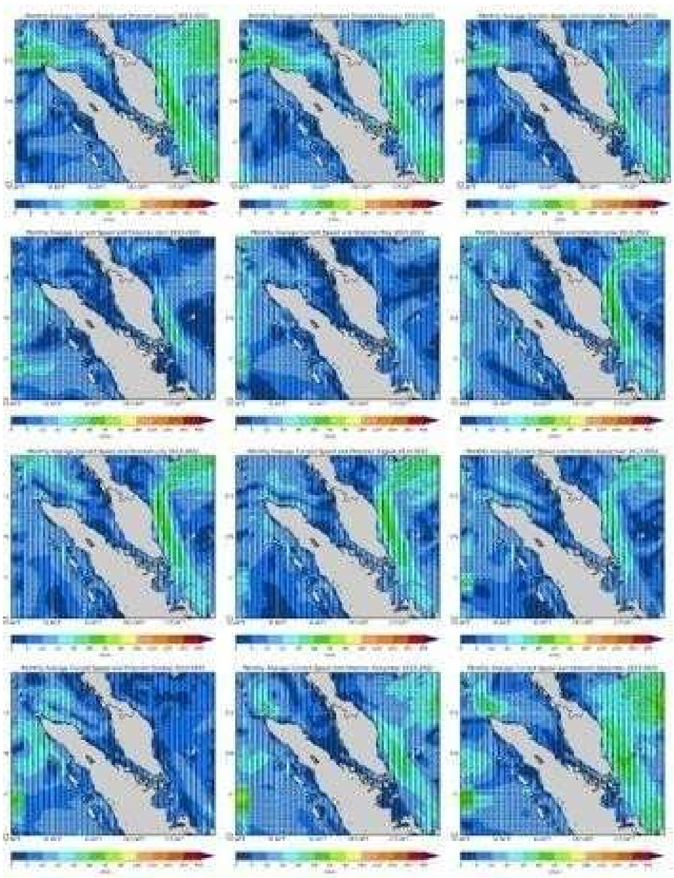

Figure 10. Average Current Climatological Data for 10 Years in The Malacca Strait

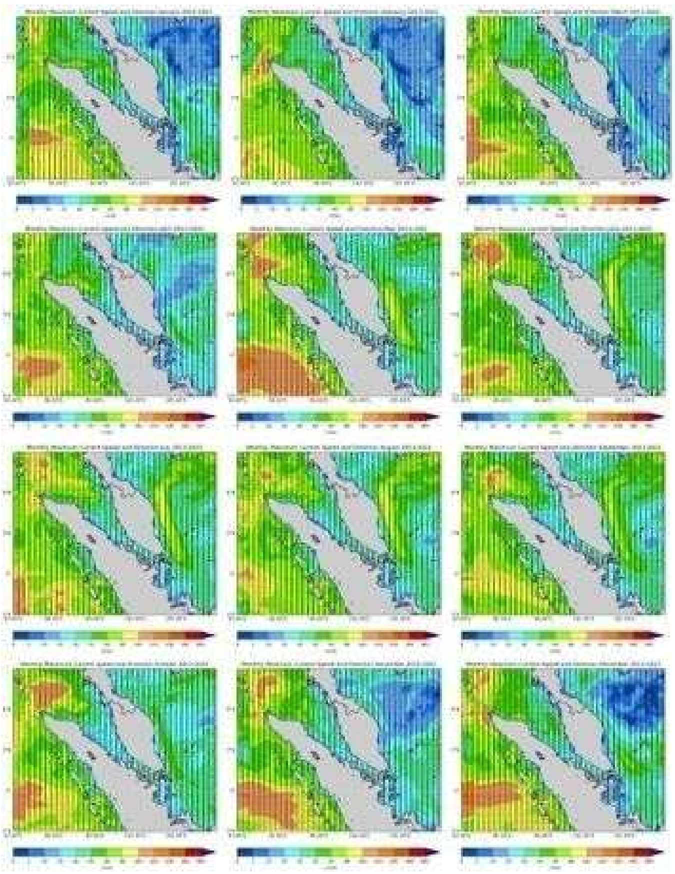

Figure 11. Maximum Current Climatological Data for 10 Years in The Malacca Strait

From Figures 10 and 11 we can see climatological data in the form of average current velocityfor 10 years in the Malacca Strait. The average current speed for 10 years in the Malacca Strait ranges from 0 - 30 cm/s with the dominant direction towards the Southeast in the northern Malacca Strait andtowards the Northwest in the southern Malacca Strait. For maritime activities inthe Malacca Strait, it is necessary to be aware of the meeting of currents from the Southeast and Northwest around the East Coast of Aceh which makes a vortex around the area. Also be aware that the maximum current speed in the Malacca Strait can reach 60 - 100 cm/s which can interfere with all activities at sea.

IV. CONCLUSION

Based on the results of the above research, it shows that the wind in the Malacca Strait on average blows from the Northwest and Southeast with an average speed of around 0 - 6 knots and a maximum speed of 20 - 30 knots (36 - 54 km / h) especially in the central and northern parts of the Malacca Strait. The average wave height in the Malacca Strait is around 0.0 -

0.5 metres with maximum wave heights reaching 3 - 5 metres. Meanwhile, the current has an average speed of around 0 - 30 cm/s with a maximum speed of 60 - 100 cm/s. Based on the climatological data of the Malacca Strait, it can be concluded that Maritime Security in terms of Shipping Safety in the Malacca Strait is quite safe, but it is necessary to be aware of sudden changesin weather conditions, especially during transitional or transitional periods.

ACKNOWLEDGMENT

The authors would like to thank all those who have helped and supported this research. Special thanks to the University of Defense Republic of Indonesia and the entire academic community.

REFERENCES

[1]. Anggara, P. D., Adrianto, D., Pranowo, W. S., & Alam, T. M. (2022). Analisis Karakteristik Gelombang Laut Guna Mendukung Data Informasi Operasi Keamanan Laut di Wilayah Laut Natuna dan Laut Natuna Utara. *Jurnal Chart Datum*, *3*(2), 107–

[2]. 131. https://doi.org/10.37875/chartdatum.v3i2.123

[3]. "Coastal Upwelling off the Northern South China Sea Coast and Its Relationship to the MonsoonWinds" by Chen, D., Wang, D.X., Tang, D. L., et al. (2003).

[4]. de Jong, S. M., Kooi, M., & Koper, R. (2012). "Exploring the use of GIS-based multidimensional datacubes in spatial decisionsupport". International Journal of Geographical Information Science, 26(3), 393-411.

[5]. Hadi, S. and I. Radjawane. (2009). Ocean Currents. Bandung Institute of Technology. Bandung. Journalof Civil Engineering,Vol 13. No. 1, pp: 11 - 22.

[6]. Henderson, F., & Vellidis, G. (2016). Spatiotemporal data mining and analysis. CRC Press.

[7]. Kadir, Abdul. (1995). Energy Resources, Innovation, Power and Economic Potential. Jakarta: Publisherof Universita Indonesia(UI-Press).

[8]. Marelsa, N. F., & Oktaviandra, Y. (2019). ANALISIS KARAKTERISTIK GELOMBANG LAUT MENGGUNAKAN SOFTWARE WINDWAVE-12 (STUDI KASUS : KEPULAUAN MENTAWAI). *OSEANA*, *44*(2), 10–24.

[9]. https://doi.org/10.14203/oseana.2019.Vol.44No.2.23

[10]. NASA. (2020). What Are NetCDF Data? Retrieved from https://earthdata.nasa.gov/learn/faq/what- are- netcdf-data.

[11]. Purba, Noir P., and Widodo, S. Pranowo. (2015). Oceanographic Dynamics, Description of Water Mass Characteristics and Seawater Circulation. ISBN: 978-602-0810-20-1 UNPAD Press, Bandung.

[12]. Rusli, M. H. B. M., Suherman, A. M., Yuliantiningsih, A., Wismaningsih, W., & Indriati, N. (2021). The Straits of Malacca and Singapore: Maritime Conduits of Global Importance. *Research in World Economy*, *12*(2), 123. https://doi.org/10.5430/rwe.v12n2p123

[13]. Sandkamp, A., Stamer, V., & Yang, S. (2022). Where has the rum gone? The impact of maritime piracy on trade and transport.

[14]. *Review of World Economics*, *158*(3), 751–778. https://doi.org/10.1007/s10290-021-00442-1

[15]. Sinaga, A. D., & Luthfia, O. M. (2019). Pengolahan Data Grib Untuk Penentuan Karakteristik Gelombang Di Perairan KarimunJawa Dengan Menggunakan Windwaves-05. *Journal Of Innovation And Applied Technology*, *05*(01), 888–897.

[16]. Unidata. (2020). NetCDF Overview. Retrieved from https://www.unidata.ucar.edu/software/netcdf/docs/netcdf_overview.html.

[17]. Wan, C., Zhao, Y., Zhang, D., & Yip, T. L. (2021). Identifying important ports in maritime container shipping networks along the Maritime Silk Road. Ocean & Coastal Management, 211(February), 105738.

[18]. https://doi.org/10.1016/j.ocecoaman.2021.105738

[19]. Wu, S. (2016). Maritime security in the South China Sea: regional implications and international cooperation. Routledge.