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The Correlation of The Mixed Layer Depth with La Nina and El Nino Index In The Natuna Basin

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ABSTRACT

The Natuna Sea is one of the seas located in the northern part of Indonesia, which is influenced by several oceanographic climate phenomena, including the El Nino-Southern Oscillation (ENSO) system, such as La Nina and El Nino, which cause vertical temperature dynamics. This study aimed to examine the relationship between La Nina, El Nino, and normal years on the variability of the mixed layer depth in the Natuna Sea. The study utilized temperature data from the World Ocean Database (WOD) and Marine Copernicus for a period of 3 years, including years with La Nina, El Nino, and normal conditions, as well as mixed layer depth (defined by sigma theta) data from Marine Copernicus. the occurrence of La Nina, El Nino and normal years obtained from the Southern Oscillation Index (SOI). The results showed that the correlation of SOI values with the depth of Maximum Mix Layer Depth (MLD) during el nino and la nina was weak and very weak during the Normal year. During the La Nina, normal, and El Nino periods, the deepest MLD occurred during the west monsoon season at depths ranging from 7 to 60 meters. The shallowest MLD occurred during the first transition season at depths ranging from 7 to 25 meters. The MLD values during the east monsoon season depths ranging from 7 to 43 meters, and during the second transition season, the MLD ranges from 7 to 44 meters.

Keywords: Mixed Layer, El Nino-Southern Oscillation (ENSO), La Nina, El Nino, North Natuna Sea

ABSTRAK

Laut Natuna merupakan salah satu laut yang berada di bagian utara Indonesia dimana masih mendapat pengaruh beberapa fenomena oseanografi iklim salah satunya yang disebut sebagai sistem El Nino Southern Oscillation (ENSO) atau La Nina dan EL Nino yang menyebabkan adanya dinamika suhu vertikal. Penelitian ini bertujuan untuk mengkaji hubungan antara La Ninia, El Nino dan tahun normal terhadap variabilitas kedalaman mixeded layer di Laut Natuna. Penelitian ini menggunakan data suhu dari World Ocean Database (WOD) dan dari Marine Copernicus selama 3 tahun yaitu pada tahun saat terjadi La Ninia, El Nino dan tahun normal dan data kedalaman mixeded layer (Ocean mixeded layer thickness defined by sigma theta) dari Marine Copernicus, data terjadinya La Nina, El Nino dan tahun normal diperoleh dari Southern Oscillation Index (SOI). Hasil penelitian menunjukkan korelasi nilai SOI dengan kedalaman Maksimum Mix Layer Depth (MLD) pada saat el nino dan la nina lemah dan sangat lemah saat tahun Normal. Pada periode la nina, normal dan el nino di dapatkan MLD terdalam terjadi saat musim barat pada Kedalaman 7 sampai 60 meter, MLD terdangkal terjadi pada musim peralihan I dengan kedalaman 7 sampai 25 meter. Nilai kedalaman MLD pada musim timur 7 sampai 43 Meter dan saat musim peralihan II MLD berada pada kedalaman 7 sampai 44 meter.

Kata kunci: Lapisan Tercampur/ Mix Layer, El Nino-Southern Oscillation (ENSO), La Nina, El Nino, Laut Natuna utara

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1. Introduction

The North Natuna Sea is one of the connections between the Pacific Ocean and the Indian Ocean. The water mass from the Pacific Ocean is channeled to the South China Sea (SCS) and then directed to the North Natuna Sea. The North Natuna Sea is located north of the Natuna Regency and is the southernmost tip of the South China Sea. The North Natuna Sea is bordered by Vietnam and Cambodia to the north, East: It is bordered by East Malaysia (Sarawak) and Kalimantan, West: It is bordered by the Malaysian Peninsula.

According to (Ramdhan, 2022), the geological formation process of the North Natuna Sea and the South China Sea basin took place hundreds of millions of years ago, resulting in oil and gas traps beneath the seabed of the North Natuna Sea and the South China Sea. As a result of the geological formation of the basin, the North Natuna Sea has shallow depths that connect to the deep bathymetry of the South China Sea basin. This basin then generates unique patterns of ocean currents, namely the Vietnam Jet Current (VJC) and the Natuna Off-Shelf Current (NOC). In fact, the VJC and NOC are part of a unified circulation pattern in the South China Sea.

ENSO stands for El Niño-Southern Oscillation, which refers to the oscillation between El Niño and La Niña phases. El Niño represents the positive phase of ENSO. El Niño occurs when sea surface temperatures (SST) in the central and eastern tropical Pacific are warmer than average. On the other hand, La Niña represents the negative phase of ENSO. La Niña occurs when SST in the central and eastern tropical Pacific are cooler than average.

The impacts of ENSO in most parts of Indonesia include very dry dry seasons and delayed onset of rainy seasons during El Niño events. Conversely, during La Niña events, the rainy season arrives earlier than usual (Safitri, 2015). The ENSO phenomenon can be identified based on the values of the Southern Oscillation Index (SOI) and the Nino 3.4 Index. The Nino 3.4 Index represents the anomaly of sea surface temperatures in the tropical ocean region (NOAA, 2023). Meanwhile, the SOI represents the difference in air pressure between Tahiti and Darwin (BOM, 2023).

Water column stratification refers to the layering of water in the deep sea. Stratification occurs due to physical characteristics of seawater such as temperature, salinity, density, and pressure. This stratification occurs vertically. Generally, the layers in the deep-sea water column are divided into three: the mixed layer depth (MLD), thermocline, and deep layer. MLD is formed due to the mixing of water masses by wind, currents, and tides at the sea surface, which causes the temperature in that layer to be relatively uniform or homogeneous (Tubulawony, 2007). The depth of the mixed layer is marked by a temperature value that approaches the surface value due to turbulence caused by waves and wind stress on the sea surface (Wijesekera and Gregg as cited in Nofiyanti, 2017).

The objective of this study is to determine the variability of the mixed layer depth in the North Natuna Sea during the occurrence of La Niña, El Niño, and normal years of ENSO over a period of 12 months. This study differs from previous studies in the North Natuna Sea in terms of variables examined, such as Significant Wave Height (Anggra et al., 2018), Natuna Off-shelf Current (Haryadi et al., 2020), Wind-Generated Currents and Tides (Riswan Ak. et al., 2019), and Wind as a Wave Generator (A. Afriady et al., 2019). This research is important to provide information in supporting naval patrol activities in the North Natuna Sea, and the findings are expected to make a positive contribution to the field of fisheries and the development of oceanographic knowledge in the North Natuna Sea, as well as providing insights for future research endeavors.

2. Materials and methods

The research methodology used is a quantitative method. Quantitative research is a type of research that employs a quantitative approach according to its paradigm (Abdullah, 2015). In conducting this research, several systematic and planned steps were taken. The depth data from Marine Copernicus stations and temperature data from World Ocean Database (WOD) were imported into the Ocean Data View (ODV) software version 552 (Schlitzer, 2020) and then exported as text files. These text data files were converted back into Microsoft Office Excel format. In Microsoft Office Excel, the calculation of the Mixed Layer depth and thermocline was performed by calculating the temperature gradient.

The calculated results were then presented in tabular form for analysis. Furthermore, the data from Marine Copernicus stations and CTD WOD were analyzed using the Root Mean Square Error (RMSE) value. The NC files obtained from Marine Copernicus contained data on Mixed Layer depth (Ocean Mixed Layer thickness defined by sigma theta) and currents, which were processed using the ODV software. The MLD data was correlated with the SOI data. The results of the processing provided a visualization of the isosurface patterns of Mixed Layer depth and currents for each month under El Niño, normal, and La Niña conditions. The plotted images were then analyzed and compared.

Location and Times Research

This research was conducted in 2023 at the hydro-oseanography laboratory of the Indonesian Naval Postgraduate Military Service School (STTAL). The study will be carried out during the occurrence of El Niño, normal years, and La Niña. The research duration will span 3 years, with 1 year allocated for each climatic condition. The study area was focused on the North Natuna Sea, with coordinates ranging from 106.5º East to 110.5º East and 3.4º North to 8.5º North (see figure 1).

Research Data

The research data consists of temperature, mixed layer depth, current, and Southern Oscillation Index (SOI) data. The temperature data is obtained from the World Ocean Database (WOD) as direct observation data (in situ), which can be downloaded from https://www.ncei.noaa.gov/products/world-ocean-database (see figure 1).

Additionally, temperature data is obtained from the station https://marine.copernicus.eu/ or CMEMS data. This data is in the form of NC files and represents model data. The data has a spatial resolution of 0.167° between data points and an average monthly temporal resolution. It is divided into 23 depths, ranging from 1 meter to 109.72 meters (see figure 1).

The mixed layer depth data (Ocean mixed layer thickness defined by sigma theta) is obtained from https://marine.copernicus.eu/. The data characteristics are similar to the temperature data from CMEMS. Ocean mixed layer thickness defined by sigma theta refers to the depth at which the density increase compared to the density at 10 meters depth corresponds to a temperature decrease of 0.2°C under local surface conditions (θ10m, S10m, P0= 0 db, surface pressure).

The temperature data obtained from the WOD and Marine Copernicus stations is used to determine the depth of the Mixed Layer Depth (MLD). Subsequently, the MLD depth data from the Marine Copernicus and CTD WOD data is subjected to error calculation using the Root Mean Square Error (RMSE) method. RMSE is an alternative method for evaluating forecasting techniques used to measure the accuracy level of a model's predictions. RMSE represents the average value of the squared error and can also be

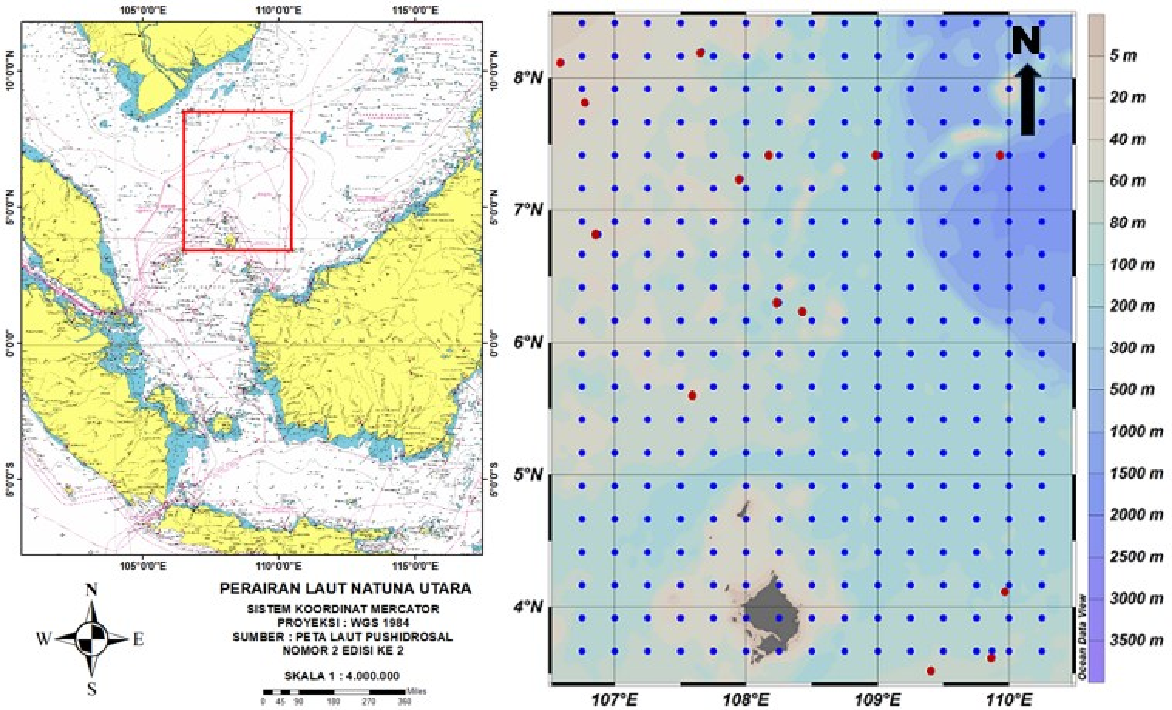

Figure 1. A. Research Location in the North Natuna Sea (Pushidrosal, 2023). B. Marine Copernicus stations and WOD stations (Red dots represent CTD WOD stations, blue dots represent Marine Copernicus stations, Color bar on the right represents the depth scale.

expressed as a measure of the magnitude of the errors generated by a forecasting model (Aryani, Fatmasari, Afriyudi & Hadinata, 2022).

$$\text{RMSE} = \left(\frac{\Sigma(y_i - \hat{y}_i)}{\text{n}}\right)^{1/2}$$

Explanation:
Yi = forecast for period t
Yt = actual value for period t
n = number of periods

Information regarding the occurrence of el niño, la niña, and normal years is obtained from the Southern Oscillation Index (SOI). These values are issued by the Australian Bureau of Meteorology and can be downloaded from http://www.bom.gov.au/climate/enso/soi/. The SOI value is calculated using a formula formulated by Troup (1965), revised by the National Climate Centre (NCC) (Boedi, 2017). The equation is as follows:

$$SOI = \frac{10\ (P_{diff} - P_{diffav})}{SD\ (P_{diff})}$$

Where: Pdiff = the difference between the monthly average sea-level pressure in Tahiti and the monthly average sea-level pressure in Darwin; Pdiffav = the long-term average of Pdiff for the specified month; SD (Pdiff) = the long-term standard deviation of Pdiff for the specified month; SOI = Southern Oscillation Index.

Sustained positive values of SOI above approximately +8 indicate the occurrence of la niña, while sustained negative values below approximately -8 indicate the occurrence of el niño (BOM, 2023). A positive SOI occurs when the air pressure in Darwin is lower than in Tahiti. This indicates that the weather conditions in the eastern Pacific region tend to be dry and hot, while the western region tends to be wet and cool. On the other hand, a negative SOI occurs when the air pressure in Darwin is higher than in Tahiti. This indicates that the weather conditions in the eastern Pacific region tend to be wet and cool, while the western region tends to be dry and hot (NOAA, 2023).

In this research, the SOI data is divided into three events, as shown in Figure 2. The first event is during the El Nino period, from March 2015 to February 2016. The SOI values during this time are as follows: -11.2, -3.8, -13.7, -12.0, -14.7, -19.8, -17.8, -20.2, -5.3, -9.1, -19.7, and -19.7. For the Normal year, data is taken from September 2016 to August 2017. The SOI values during this period are: 13.5, -4.3, -0.7, 2.6, 1.3, -2.2, 5.1, -6.3, 0.5, -10.4, 8.1, and 3.3. Lastly, for the La Nina year, data is taken from March 2022 to February 2023, with the following SOI values: 13.8, 22.6, 17.1, 21.2, 8.7, 9.1, 18.3, 17.7, 4.6, 20, 11.8, and 10.5.

These SOI values will be correlated with the MLD values. Correlation analysis is a statistical technique used to measure the strength of the relationship or correlation between two variables. The correlation is expressed by the correlation coefficient, which represents the strength of the relationship between the two variables (Gogtay & Thatte, 2017). The correlation coefficient ranges between -1.0 and +1.0. As the value approaches 1, the correlation becomes stronger, while negative and positive values indicate the direction of the relationship Arditama (Ardhitama & Sholihah , 2013).

The table 1 of correlation coefficient values can be explained as follows A. Hidayat, Efendi, Agustina, & Winars, (2018). The correlation

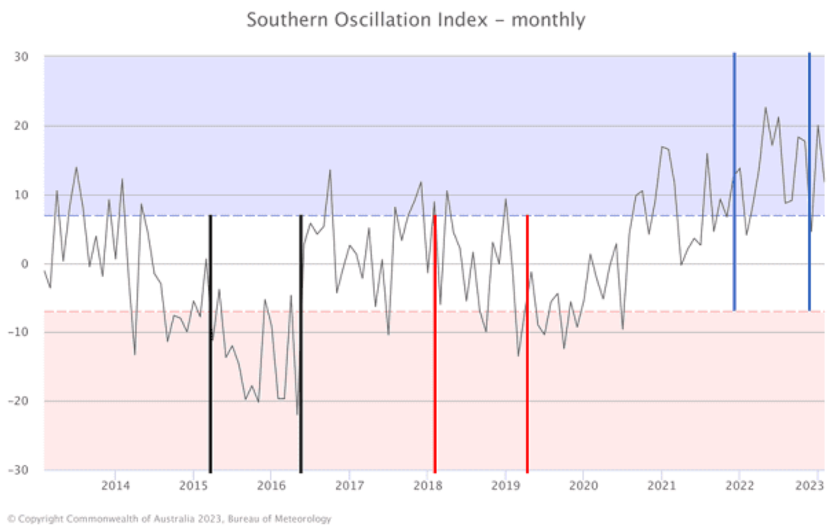

Figure 2. Range of SOI data (El Niño between two black lines, Normal between two red lines, and La Niña between two blue lines). Source (http://www.bom.gov.au/climate/enso/soi/).

Table 1. Classification of correlation coefficient values (r)

Value of r	Description
0.00 – 0.199	Very Weak
0.20 – 0.399	Weak
0.40 – 0.599	Moderate
0.60 – 0.799	Strong
0.80 – 1.000	Very Strong

coefficient can be calculated using the formula Amalia, Wirasatriya, & Widiaratih (2023).

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{n\sum X^2 - (\sum X)^2}\ \sqrt{n\sum Y^2 - (\sum Y)^2}}$$

Where r: Correlation coefficient value; Σ(X): Sum of observations for variable X; Σ(Y): Sum of observations for variable Y; Σ(XY): Sum of the products of X and Y; $\Sigma(X^2)$: Sum of squares of observations for variable X; $\Sigma(X)^2$: Square of the sum of observations for variable X; $\Sigma(Y^2)$: Sum of squares of observations for variable Y; $\Sigma(Y)^2$: Square of the sum of observations for variable Y; n: Number of paired observations of X and Y.

The current data used uses modelled data from https://marine.copernicus.eu/ or CMEMS data. The characteristics of this current data are the same as the temperature data which has a spatial range between points of 0.167° and an average monthly temporal resolution.

3. Results and Discussion

The results of data processing are presented in figures, tables, and diagrams. The isosurface plots provide information on the depth of the MLD and the ocean currents throughout the year. The isosurface plots display the conditions for three climate scenarios: El Nino year, Normal year, and La Nina year. The data is presented on a monthly basis. The color bar on the right side of the figure represents the depth variation expressed in meters (m). The arrows in the figure indicate the direction of the currents, with the scale indicating the velocity of the currents in m/s.

The comparison of Mixed Layer Depth (MLD) from WOD and Marine Copernicus data and the determination of the Root Mean Square Error (RMSE).

There are several methods to determine MLD, such as the 20° isotherm method and the vertical temperature gradient method (Peng, 2018). In this study, the vertical temperature gradient method is used. The vertical temperature gradient threshold used is 0.05 °C Bereau (1992) (Hao, 2012). The upper limit of the thermocline is considered as the depth of the MLD.

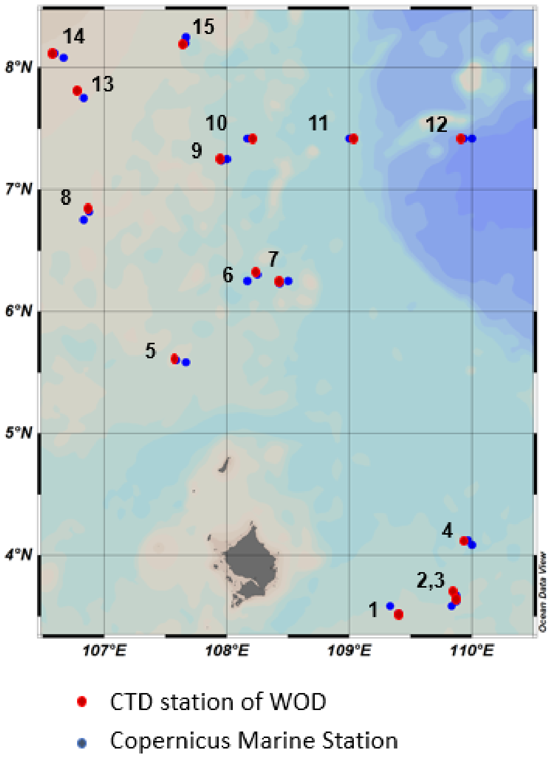

Figure 3. The distribution of stations that are compared.

The CTD data used is obtained from the WOD dataset (red dots) and the data from the Marine Copernicus station (blue dots), as shown in Figure 3. The Marine Copernicus station selected is the nearest station to the coordinates of the CTD from WOD, and the data is collected for the same month. It is expected that using the nearest station ensures similar depth characteristics.

From the processing results (Table 2), it can be observed that the MLD thickness from the CTD stations is deeper compared to the data from Marine Copernicus. This difference can be attributed to the significant time gap between data collection. To determine the error value between these two datasets, the Root Mean Square Error (RMSE) calculation is performed. The calculated RMSE values for MLD thickness at CTD and Marine Copernicus stations are as follows: 15.09 during El Nino, 17.10 during La Nina, and 14.88 during normal years. These values indicate the deviation between the MLD values obtained from the model data processing and the field data processing. The threshold value for accepting the accuracy of the model data based on RMSE verification is 0.4 or 40% according to Fahlevi

Table 2. Comparison of MLD Depths from CTD WOD and Marine Copernicus Stations.

No	CTD WOD Station		Marine Copernicus Station		
	Station	CTD	El Nino (m)	Normal (m)	La Nina (m)
1	1 (July 1989)	36	34.3	29.4	29.4
2	2 (July 1989)	26	34.4	29.4	29.4
3	3 (July 1989)	41	34.4	29.4	29.4
4	4 (May 1989)	20	15.8	11.4	18.4
5	5 (March 1981)	15	15.8	9.57	2.6
6	6 (March 1981)	30	18.4	9.57	5
7	7 (August 1961)	50	34.4	55.7	40.3
8	8 (January 1982)	55	34.4	34.4	40.3
9	9 (March 1981)	40	15.8	9.57	6.4
10	10 (October 1985)	54	29.4	34.4	34.4
11	11 (October 1985)	54	21.5	40.3	29.4
12	12 (October 1985)	43	34.4	34.4	29.4
13	13 (November 1988)	32	34.4	34.4	34.4
14	14 (November 1988)	28	40.3	15.8	15.8
15	15 (March 1981)	35	34.4	55.7	9.5

(2022) & Hermialingga, Purwiyanto, & Iskandar (2018). As the RMSE value approaches zero, the model data used becomes closer to the in-situ/observed data (Haiyqal et al., 2023).

ENSO Correlation with Mixed Layer Depth (MLD)

The visualization of maximum MLD depth is presented for each month during El Nino, La Nina, and normal events. The correlation between the maximum MLD values in each cycle and their corresponding SOI values is calculated. The correlation value during El Nino is R = -0.220, during normal years it is R = 0.046, and during La Nina it is R = -0.129 (see figure 4). These correlation values indicate a weak correlation during El Nino and La Nina events, and a very weak correlation during normal years. Based on these correlation results, it can be concluded that the ENSO events in the North Natuna Sea have a weak correlation with MLD depth, which is in line with (Aldrian & Susanto, 2003) who studied the climate characteristics in Indonesia based on rainfall variability and its relationship with the large-scale climate phenomenon ENSO, stating that the signal related to ENSO is suppressed

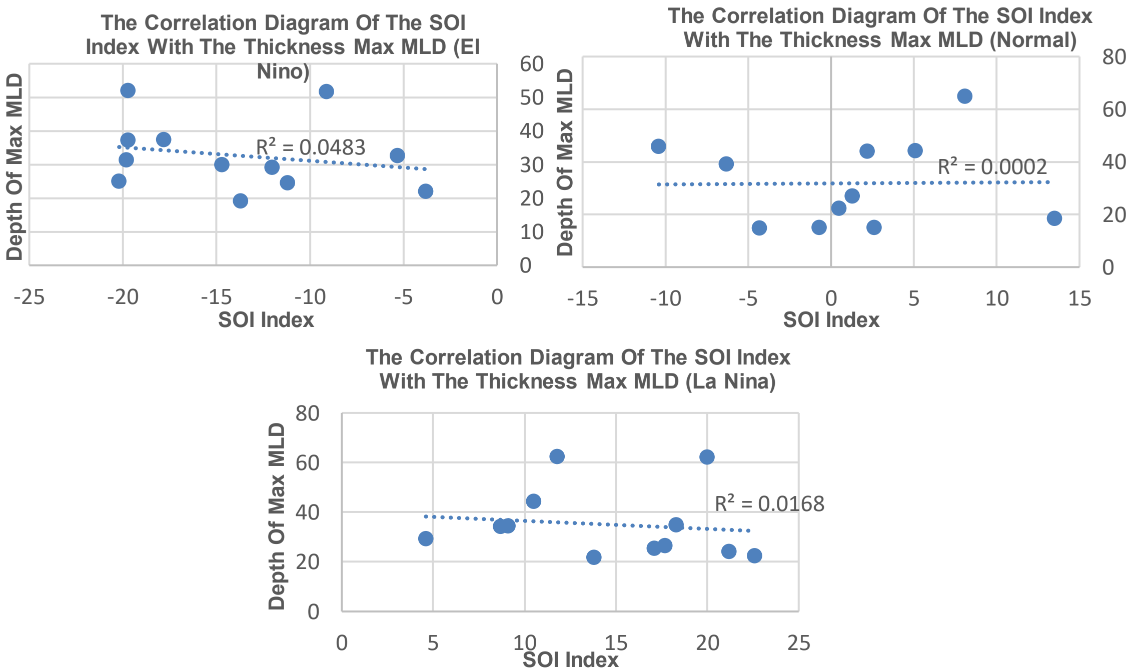

Figure 4. Correlation between SOI Index and Maximum MLD Thickness.

in the northwestern region of Indonesia, from northern Sumatra to northwestern Kalimantan. The negative correlation values during El Nino and La Nina indicate that during negative SOI values or El Nino events, the MLD depth will be shallower. On the other hand, during positive SOI values, the MLD depth will be deeper. This is consistent with (Susanto, Gordon, & Zheng, 2001), which states that during El Nino, the thermocline depth is shallower than during La Nina. Other studies have also explained that during the La Nina period, there is an accumulation of water mass in the western Pacific, which causes the upper thermocline boundary to be pushed deeper (Saji et al., 1999) & Sidabutar (2014).

Schematic of Mixed Layer Depth and Seasonal Current Patterns during Enso

The mixed layer is characterized by the mixing of water masses caused by wind, currents, and tides, making it a homogeneous layer (Wyrtki, 1961). Additionally, this layer is still penetrated by sunlight. As a result, the conditions in the mixed layer undergo temporal and spatial variations. In this study, not all isosurface plots are presented. To represent the studied conditions, plots are selected for the months of April, June, October, and January. These months are considered to represent the four seasons that occur in the research area (see figure 5).

During the El Nino phase (see figure 5 A), in the transitional season I, the maximum MLD depth is 24.6 meters in March, and it becomes shallower at 7 meters each month. Moving into the South-East Season, the MLD values range from 7 to 33.5 meters. The maximum depth occurs in July. During transitional season II, the MLD depths range from 7 to 37 meters, with the maximum depth occurring in September. In the North-West Season, the MLD depths range from 7 to 52 meters, with the maximum depth occurring in February.

In the normal phase (see figure 5 B), during transitional season I, the MLD depths range from 7 to 18 meters, with the maximum depth occurring in March. In the South-East Season, the deepest MLD occurs in August, reaching 43.9 meters, while the shallowest depth remains at 7 meters each month. During transitional season II, the MLD depths range from 7 to 44 meters, with the deepest depth occurring in September. Moving into the North-West Season, the MLD depths are detected within the range of 7 to 64 meters, with the maximum depth occurring in January.

Entering the La Nina phase (see figure 5 C), during transitional season I, the MLD depths range from 7 to 25.3 meters, with the deepest MLD occurring in May. During the South-East Season, the MLD values range from 7 to 34.2 meters, with the maximum depth occurring in August. In transitional season II, the maximum MLD depth occurs in September, reaching 34.7 meters, while the shallowest depth remains at 7 meters. During the North-West Season, the MLD depths range from 7 to 62 meters. The maximum depths are observed in December and January.

During the transitional season I, which includes El Niño, normal, and La Niña conditions, the mixed layer depth (MLD) in the North Natuna Sea is shallow, ranging from 7 to 25 meters from March to May. During the North-West Season, the MLD becomes the deepest, ranging from 7 to 62 meters. This pattern is influenced by the wind patterns, especially the monsoon winds, which significantly affect the mixing of water masses in the mixed layer. Previous studies have explained that stronger winds generate stronger currents and waves, which stir the water masses in the marine column, resulting in a deeper mixed layer and a downward movement of the thermocline (Hutabarat, 2018).

Overall, the MLD in the North Natuna Sea is shallow during transitional season I (March-April), becomes deeper during the South-East Season (June-August), experiences a shallow depth again during transitional season II (September-November), and undergoes a thickening during the North-West Season (December-February). This has been previously discussed (Thompson & Tkalich, 2014). In the southern part of the South China Sea, the MLD variation is similar. It is deeper during June-August (summer) and December-February (winter), and shallow during March-May (spring) and September-October (autumn).

The current plot results indicate that from March to May, the currents originate from the east and have small scales. According to Hariyadi (2021), during the first transitional season, weak ocean currents dominate around the South China Sea and the North Natuna Sea. By July-August, dominant currents shift from the west and tend to turn northward. Previous research, as explained by Maisyarah (2019), indicates that during the east monsoon season, there is a noticeable northward movement of currents. In September, the currents come from both the west and east directions. In October, the currents originate from the north. Moving into November, dominant currents come from

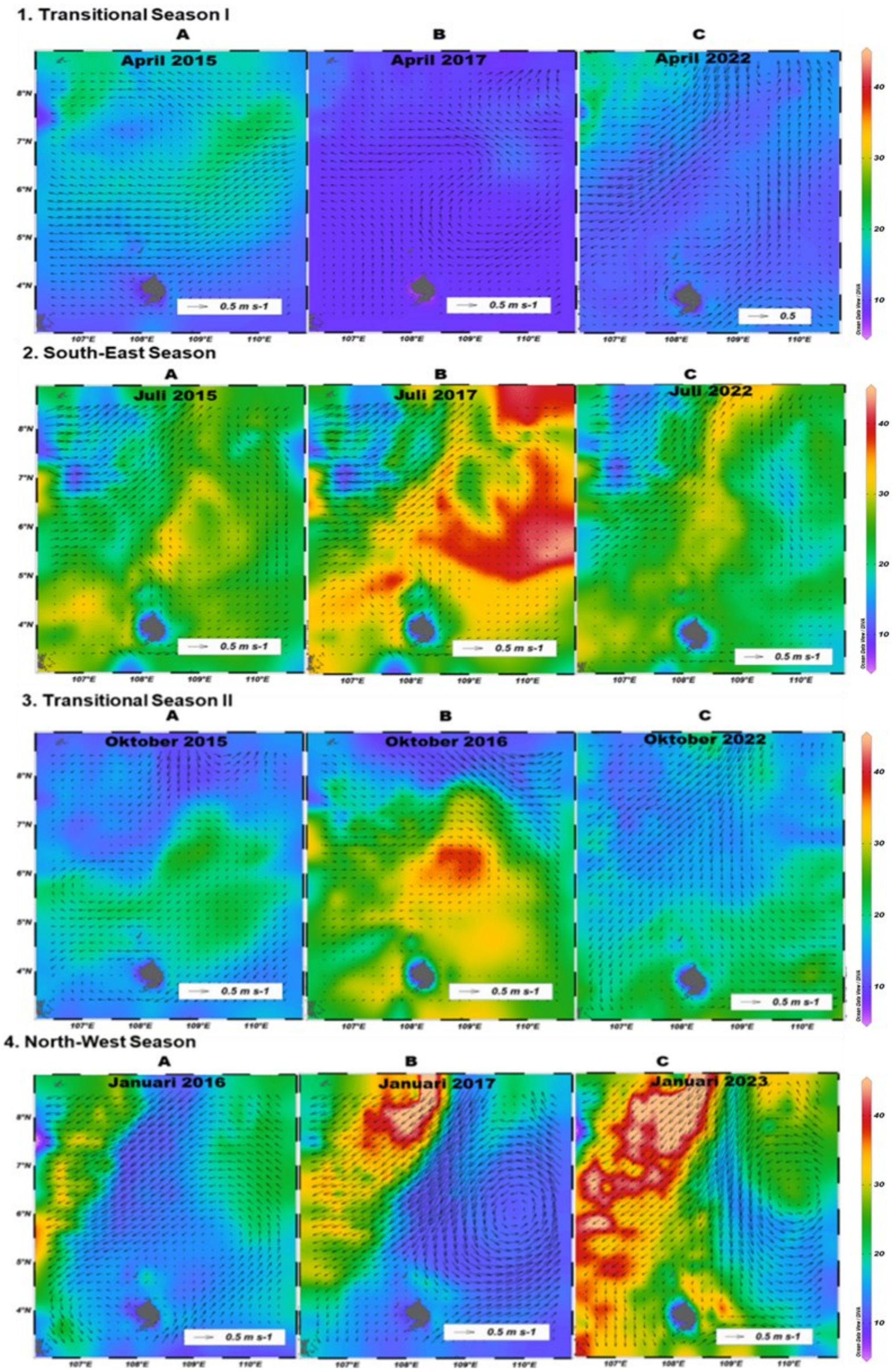

Figure 5 The isosurface of Mixed Layer Depth (MLD) and ocean currents in North Natuna for the El Nino (A), Normal (B), and La Nina (C) phases. The color bar on the right side of the figure indicates the of MLD.

the north, but weaker currents from the south are observed. During the North-West Season from December to February, dominant currents come from both the north and south directions. The convergence of strong currents from the north and south forms eddies in the North Natuna Sea, as described in another study by Mujiasih (2023). Within the North Natuna Sea,

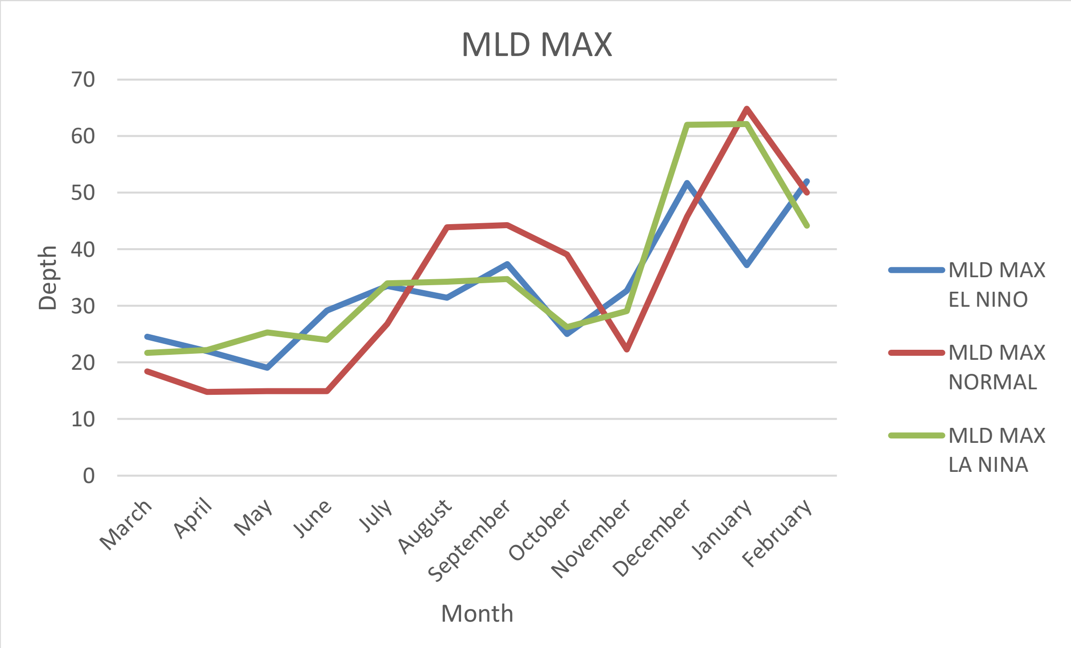

Figure 6. Comparison of maximum MLD (Mixed Layer Depth) during El Niño (blue), normal (red), and La Niña (green).

there are three phenomena: the Vietnam Coastal Jet (VCJ), the Natuna Off-shelf Current (NOC), and the Natuna Island Eddy (NIE). Wyrtki, as mentioned by Hariyadi (2021), first discovered the NOC, which describes the extension of the VCJ, resulting in the circulation of the NOC in the North Natuna Sea, which produces cyclonic eddies.

From Figure 6, it can be observed that the pattern of maximum MLD (Mixed Layer Depth) during El Niño, normal, and La Niña conditions shows a similar pattern. During the first transitional season (March-May), the MLD tends to be shallow. As the South-East Season begins (June-August), the MLD thickens. It then undergoes a shallowing trend during the second transitional season (September-November) and thickens again during the North-West Season (December-February). The pattern of maximum MLD depth is likely influenced by the seasonal patterns in the North Natuna Sea. During the transitional seasons, the weakening of winds is different compared to the southeast monsoon winds during the South-East Season. The deepening during the North-West Season may be due to the proximity of the North Natuna Sea to the Asian continent, where north winds prevail. Overall, the MLD thickness pattern changes in accordance with the seasonal variations, as supported by Thompson & Tkalich (2014). The MLD in the southern part of the South China Sea exhibits remarkable seasonal variations influenced by the monsoons.

4. Conclusion

The conclusion of this study is that the correlation of the soi index with maximum depth of MLD in the period el nino and la nina had a weak correlation and in the normal period had a very weak correlation. In the period of El Nino, normal period and the la nina period of maximum depth MLD occurs during the North-West Season. With a depth range of 7-60 meters. And shallow during transitional season I. With a depth range of 7-25 meters. MLD depth value in South-East Season reaches 7-43 meters. And MLD depth in season transition II in the range of 7-44 meters. Suggestions for future research include a more detailed discussion of the direction and magnitude of the currents in the North Natuna Sea, as well as the data and influence of the wind that occurred at that time.

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