
Analysis of Upwelling Parameters when the El Nino Southern Oscillation (ENSO) Occurred in the Halmahera Sea

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Abstract

Upwelling events that occur in the Halmahera Sea are influenced by the El Nino Southern Oscillation (ENSO). Upwelling can cause sea surface temperatures to be lower than normal, affecting the potential of fishery resources in the region. The purpose of this study was to determine the conditions of sea surface temperature, chlorophyll-a content, salinity, and upwelling conditions when viewed from the parameters of chlorophyll- α content and sea surface temperature when El Nino was strong, El Nino was weak, La Nina was strong, and La Nina weak and in normal conditions in the Halmahera Sea region. The data used in this study include the Oceanic Nino Index, sea surface temperature, salinity, and chlorophyll- α content during the 2010–2019 period. A quantitative descriptive research type is used by filtering ENSO data to determine when ENSO occurred, then visualizing the data in each parameter and analyzing it. The results of this study show that upwelling is known to occur in the northern to western parts of the Halmahera Sea. When the El Nino phase is vital, the upwelling parameter changes, the sea surface temperature decreases to 27.1°C, the chlorophyll- α content increases to 0.70 mg/m³ compared to the normal phase, and the upwelling intensity changes.

1. Introduction

The interaction between the ocean and the atmosphere in tropical regions causes several phenomena, such as the Madden-Julian Oscillation (MJO), Indian Ocean Dipole (IOD), monsoon winds, El Nino Southern Oscillation (ENSO), cold surges, and others. These phenomena can influence weather parameters such as rainfall, wave height, sea surface temperature, current surface, etc. One of the phenomena that can result from this interaction between the ocean and the atmosphere is El Nino Southern Oscillation (ENSO).

El Nino Southern Oscillation (ENSO) is an ocean interaction phenomenon in the atmosphere which is characterized by changes in sea surface temperature (SST) in the Pacific Ocean region, precisely in the eastern and central parts of the equatorial Ocean Pacific

with a cycle period of around 4 to 6 years, and can have an impact globally (Quispe, 2018). According to Aldrian (2008), ENSO oscillations consist of two phenomena, El Nino and La Nina, whose events are related and occur successively with a cold phase and a warm phase in the region of the equatorial Pacific Ocean. The variability of global climate anomalies that occur, namely ENSO, is closely related to understanding upwelling variability. During El Nino, upwelling occurs south of Bali to the Savu Sea, Nusa Tenggara Timur becomes strong. On the other hand, upwelling at that location becomes fragile during La Nina.

The Halmahera Sea is one of the crucial waters for developing Indonesia's climate, specifically, and the world's climate in general. As part of the Western Pacific Warm Pool (WPWP), this sea also serves as a center for

heat convection that will be distributed to higher latitudes through interactions between the sea and the atmosphere. It is also an area highly influenced by ENSO circulation. The Halmahera Sea is traversed by a branch of the global ocean current system (thermohaline circulation), which passes through Indonesian waters and is known as the Indonesian Throughflow (Arlindo). The Halmahera Sea is one of the entry points for Pacific Ocean water masses, with a small portion of North Pacific and South Pacific waters entering the Banda Sea through the Halmahera Sea and subsequently flowing into the Indian Ocean (Hasanudin, 1998). Upwelling can also be analyzed based on sea level anomaly. Sea levels in areas where upwelling occurs during tropical cyclone events will be lower than in the surrounding areas and vice versa (Lentz, 2010). The decrease in sea level during upwelling occurs because water masses move in opposite directions, creating a void on the sea surface. The void created by the movement of water masses in opposite directions causes sea level to be higher in the upwelling area than its surroundings (Colling et al., 2004).

This research will analyze the influence of ENSO on the occurrence of upwelling in the Halmahera Sea using sea surface temperature (SST), chlorophyll- α , and salinity as parameters. According to Kunarso et al. (2005), maps containing information about the distribution of sea surface temperature (SST) and chlorophyll- α content can facilitate the identification of areas with potential fisheries. This is further supported by research conducted by Inaku (2015), which states that an increase in chlorophyll- α content can indicate upwelling, with the upwelling pattern starting in June, peaking in August, and weakening in October. By analyzing the occurrence of upwelling, it is hoped that this information can be used to identify regions with potential in the fisheries sector. The Halmahera Sea is part of Indonesia's potential Fisheries Management Area (WPP - Wilayah Pengelolaan Perikanan) 715. The fisheries sector in the Halmahera Sea reaches 69,438,248 tons per year. The results of this research are expected to support maritime activities, especially fishing, in the Halmahera Sea and its vicinity.

2. Methodology

The data used in this study are as follows: Oceanic Nino Index (ONI) to Evaluate

Oceanic Nino Index data from 2010 to 2020 to determine the timing of ENSO occurrences and regular periods. The ENSO criteria used are as follows: strong El Nino with an index $\geq 1.5^{\circ}\text{C}$, weak El Nino with an index $>0.5^{\circ}\text{C}$ and $<1.5^{\circ}\text{C}$, weak La Nina with an index $\leq -0.5^{\circ}\text{C}$ and $>-1.5^{\circ}\text{C}$, strong La Nina with an index $\leq -1.5^{\circ}\text{C}$, and typical conditions when the index falls within the range of $>-0.5^{\circ}\text{C}$ and $<0.5^{\circ}\text{C}$ from the National Oceanic and Atmospheric Administration (NOAA), which can be accessed online at <https://origin.cpc.ncep.noaa.gov/>. Sea Surface Temperature (SST) and chlorophyll-a data from the National Aeronautics and Space Administration (NASA) can be obtained online at <https://oceancolor.gsfc.nasa.gov/>. Salinity data from the Copernicus website can be obtained online at <http://marine.copernicus.eu/>.

3. Result and Discussion

The strong El Nino, weak El Nino, strong La Nina, and weak La Nina phases are compared to the neutral phase that occurred in 2013, with the neutral phase having Ocean Nino Index values within the range of -0.5 to 0.5 in each DJF, MAM, JJA, and SON period. Ocean parameters such as sea surface temperature, chlorophyll-a, and salinity were used to assess upwelling conditions in the Halmahera Sea region. The strong El Nino, weak El Nino, strong La Nina, and weak La Nina phases were evaluated regarding sea surface temperature, chlorophyll- α , and salinity as key parameters to assess upwelling conditions in the Halmahera Sea region. The selection of annual periods for the El Nino Southern Oscillation based on Ocean Nino Index values to determine strong El Nino, weak El Nino, strong La Nina, and weak La Nina phases can be seen in Table 1.

Table 1. The selection of ENSO Phases

Fase ENSO	Periode	ONI
El Nino strong	DJF 2016	2,5
El Nino weak	DJF 2014	0,6
La Nina strong	SON 2010	-1,6
La Nina weak	SON 2017	-0,8

In Table 1, the strong El Nino phase occurred in the DJF 2016 period with an Ocean Nino Index value of 2.5. The weak El Nino phase occurred in the DJF 2014 period with an ONI value of 0.6. The strong La Nina phase occurred in the SON 2010 period with an

Ocean Nino Index value of -1.6. The weak La Nina phase occurred in the SON 2017 period with an Ocean Nino Index value of -0.8.

3.1. Strong El Nino

Sea surface temperature conditions during a strong El Nino phase exhibit a range of temperatures from 24.5°C to 30.86°C (Figure 1). The northern to western parts of the Halmahera Sea display a significant variation in sea surface temperature values, ranging from 24.9°C to 27.10°C. The eastern part of the Halmahera Sea shows similarities to the western region. However, the range of sea surface temperature values in the eastern part is not as extensive as in the northern to western areas. The distribution of sea surface temperature values in the eastern part of the Halmahera Sea ranges from 25°C to 28.20°C. The southern part of the Halmahera Sea exhibits higher sea surface temperature values than the northern, western, and eastern regions, with temperatures ranging from 27.50°C to 29.37°C.

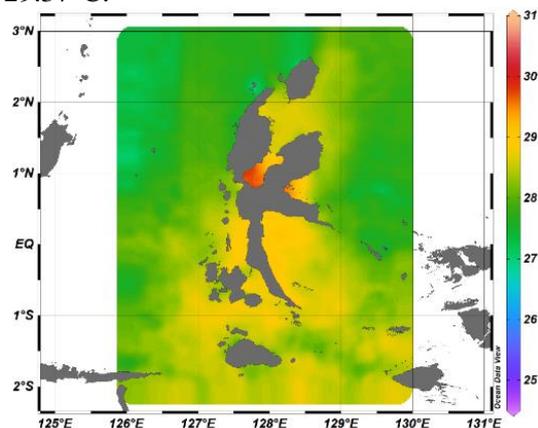


Figure 1. Sea Surface Temperature Conditions during Strong El Nino Phase

The distribution of sea surface temperature values undergoes a significant change during a strong El Nino phase, ranging from 24.5°C to 30.86°C, compared to the distribution of sea surface temperature during normal conditions, which ranges from 24°C to 30.31°C. Higher sea surface temperature values with a broader distribution occur during typical phases. The El Nino phase experiences a decrease in sea surface temperature values with a distribution of colder and wider sea surface temperatures compared to normal conditions. The distribution of sea surface temperature

during the regular phase ranges from 27°C to 29°C. In contrast, during a strong El Nino phase, it ranges from 24.9°C to 27.10°C, causing the western part of the Halmahera Sea to experience a decrease of up to 2.1°C. The distribution of sea surface temperature during the regular phase ranges from 26°C to 28.63°C. In comparison, during a strong El Nino phase, it ranges from 25°C to 28.20°C, resulting in a decrease in sea surface temperature of up to 1°C in the eastern part of the Halmahera Sea.

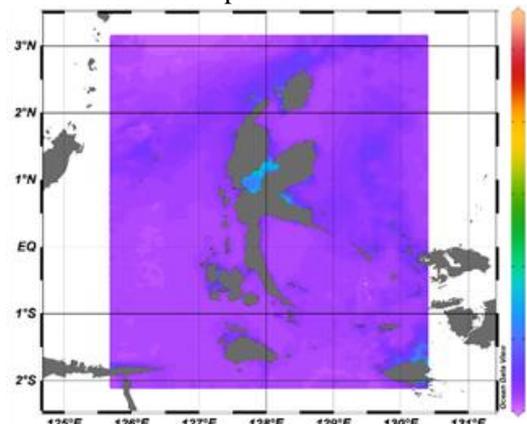


Figure 2. Chlorophyll-a Conditions during Strong El Nino Phase

Figure 2, chlorophyll- α distribution during a strong El Nino phase shows a range of chlorophyll- α values from 0.05 mg/m³ to the highest value of 5.15 mg/m³ in coastal areas. The northern to western parts of the Halmahera Sea display a distribution of chlorophyll- α values ranging from 0.27 mg/m³ to 1.05 mg/m³. The eastern part of the Halmahera Sea exhibits a distribution of chlorophyll- α values ranging from 0.29 mg/m³ to 0.58 mg/m³. The southern part of the Halmahera Sea has a distribution of chlorophyll- α values ranging from 0.10 mg/m³ to 0.40 mg/m³.

A strong El Nino phase changes chlorophyll- α values compared to normal conditions. The distribution of chlorophyll- α during the regular phase ranges from 0.04 mg/m³ to the highest value of 3.84 mg/m³ in coastal areas. In comparison, during a strong El Nino phase, chlorophyll- α distribution ranges from 0.05 mg/m³ to the highest value of 5.15 mg/m³ in coastal areas. During the regular phase, the eastern part of the Halmahera Sea shows a chlorophyll- α distribution ranging from 0.10 mg/m³ to 0.38 mg/m³.

In contrast, during a strong El Nino phase, it ranges from 0.29 mg/m³ to 0.58 mg/m³, increasing chlorophyll- α values. The

northern to western parts of the Halmahera Sea during the regular phase exhibit a chlorophyll- α distribution ranging from 0.17 mg/m³ to 0.30 mg/m³, while during a strong El Nino phase, it ranges from 0.27 mg/m³ to 1.05 mg/m³, leading to an increase in chlorophyll- α values in the western part of the Halmahera Sea. During the regular phase, the Halmahera Sea's southern part displays a chlorophyll- α distribution ranging from 0.17 mg/m³ to 0.35 mg/m³. In contrast, during a strong El Nino phase, it ranges from 0.10 mg/m³ to 0.40 mg/m³, increasing chlorophyll- α values in the western part of the Halmahera Sea.

Distribusi Spasial Salinitas Saat Fase El Nino Kuat

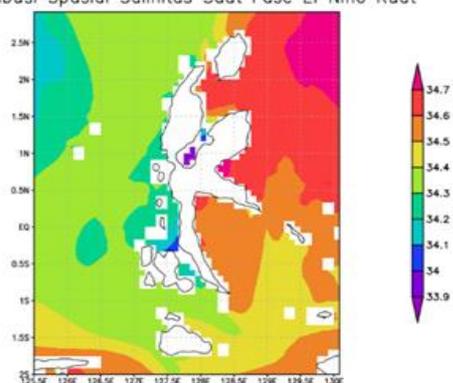


Figure 3. Salinity Conditions during Strong El Niño Phase

The distribution of sea surface temperature values undergoes a significant change during a strong El Niño phase, ranging from 24.5°C to 30.86°C, compared to the distribution of sea surface temperature during normal conditions, which ranges from 24°C to 30.31°C. Higher sea surface temperature values with a broader distribution occur during typical phases. The El Niño phase experiences a decrease in sea surface temperature values with a distribution of colder and wider sea surface temperatures compared to normal conditions. The distribution of sea surface temperature during the regular phase ranges from 27°C to 29°C.

In contrast, during a strong El Niño phase, it ranges from 24.9°C to 27.10°C, causing the western part of the Halmahera Sea to experience a decrease of up to 2.1°C. The distribution of sea surface temperature during the regular phase ranges from 26°C to 28.63°C. In comparison, during a strong El Niño phase, it ranges from 25°C to 28.20°C, resulting in a decrease in sea surface temperature of up to 1°C in the eastern part of the Halmahera Sea

3.2. Strong La Niña

The sea surface temperature conditions during a substantial La Niña phase range from 24.81°C to 30.42°C. The northern to western parts of the Halmahera Sea display a significant variation in sea surface temperature values, ranging from 28.88°C to 29.77°C. The eastern part of the Halmahera Sea experiences an increase in sea surface temperature values almost similar to the northern to western parts of the Halmahera, with a range of 29.03°C to 29.50°C. The southern part of the Halmahera Sea has a distribution of sea surface temperature ranging from 28.20°C to 29.18°C (Figure 4).

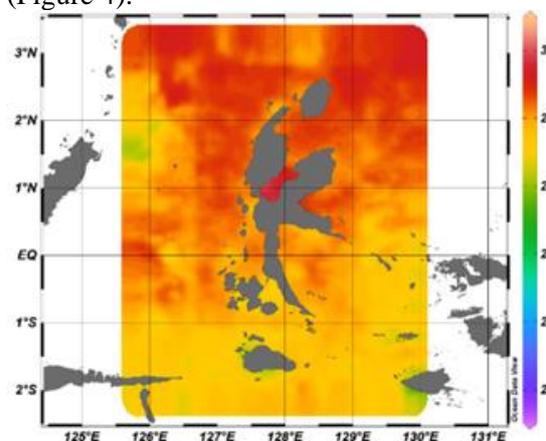


Figure 4. Sea Surface Temperature Conditions during Strong La Niña Phase

A strong La Niña phase increases sea surface temperature values with a distribution of sea surface temperatures compared to normal conditions. The distribution of sea surface temperature during normal conditions ranges from 23.24°C to 30.21°C. In comparison, during a strong La Niña phase, it ranges from 24.81°C to 30.49°C, causing sea surface temperatures in Halmahera to increase by up to 1.57°C. The distribution of sea surface temperature in the eastern part of Halmahera during normal conditions ranges from 27.37°C to 30.10°C. In contrast, during a strong La Niña phase, it ranges from 28.69°C to 29.56°C, increasing sea surface temperature by up to 1.32°C. The distribution of sea surface temperature in the western part of Halmahera during normal conditions ranges from 27.37°C to 30.10°C. In comparison, during a strong La Niña phase, it ranges from 28.81°C to 30.20°C, causing an increase in sea surface temperature by up to 1.44°C

The distribution of chlorophyll- α during a strong La Nina phase shows a range of chlorophyll- α values from 0.05 mg/m³ offshore to the highest value of 3.46 mg/m³ in coastal areas. The northern to western parts of the Halmahera Sea exhibit a distribution of chlorophyll- α values ranging from 0.10 mg/m³ to 0.20 mg/m³. The eastern part of the Halmahera Sea displays chlorophyll- α values ranging from 0.13 mg/m³ to 0.30 mg/m³. In comparison, the southern part of the Halmahera Sea has a distribution of chlorophyll- α values ranging from 0.11 mg/m³ to 0.24 mg/m³, as shown in Figure 5.

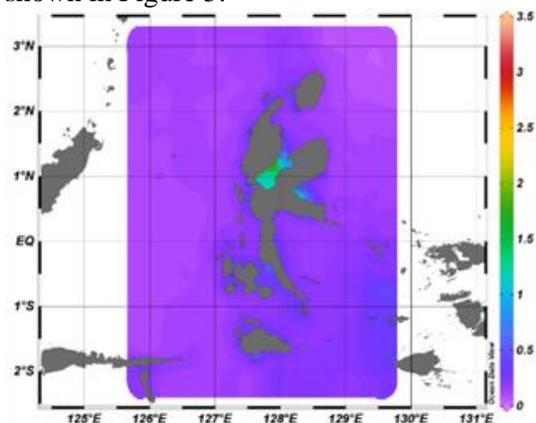


Figure 5. Sea Surface Temperature Conditions during Strong La Nina Phase

A strong La Nina phase changes chlorophyll- α values compared to normal conditions. The distribution of chlorophyll- α during a strong La Nina phase ranges from 0.05 mg/m³ to the highest value of 3.46 mg/m³, in contrast to normal conditions where it ranges from 0.03 mg/m³ to the highest value of 30.14 mg/m³. The distribution of chlorophyll- α in the eastern part of the Halmahera Sea during normal conditions ranges from 0.10 mg/m³ to 0.20 mg/m³. In comparison, during a strong La Nina phase, it ranges from 0.12 mg/m³ to 0.38 mg/m³, resulting in a change in chlorophyll- α values by 0.02 mg/m³ in the eastern part of the Halmahera Sea. The distribution of chlorophyll- α in the western part of the Halmahera Sea during normal conditions ranges from 0.09 mg/m³ to 0.15 mg/m³.

In contrast, during a strong La Nina phase, it ranges from 0.10 mg/m³ to 0.14 mg/m³, causing a change in chlorophyll- α values by 0.01 mg/m³ in the western part of the Halmahera Sea. The distribution of chlorophyll- α in the southern part of the

Halmahera Sea during normal conditions ranges from 0.09 mg/m³ to 0.13 mg/m³. In comparison, a strong La Nina phase ranges from 0.16 mg/m³ to 0.29 mg/m³, resulting in a change in chlorophyll- α values by 0.03 mg/m³ in the southern part of the Halmahera Sea.

The salinity distribution during a strong La Nina phase shows values ranging from 33.4 to 34.6 PSU. The eastern part of the Halmahera Sea has higher salinity values, ranging from 34.4 to 34.6 PSU. The southern part of the Halmahera Sea exhibits more varied salinity values, ranging from 33.6 to 34.4 PSU. The western part of the Halmahera Sea has lower salinity values than the eastern part, with values ranging from 33.6 to 34 PSU (Figure 6).

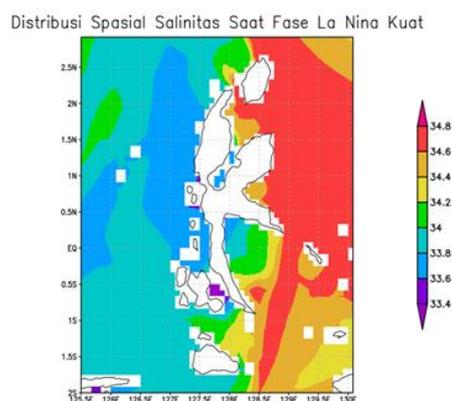


Figure 6. Salinity Conditions during Strong La Nina Phase

The salinity distribution undergoes a significant change during a strong La Nina phase, with values ranging from 33.4 to 34.6 PSU, compared to the distribution of salinity values during normal conditions, which ranges from 33.7 to 34.1 PSU. Salinity values during a strong La Nina phase in the eastern part of the Halmahera Sea range from 34.4 to 34.6 PSU, compared to salinity values during normal conditions that range from 33.8 to 34.1 PSU, increasing salinity values of up to 0.6 PSU.

The western part of the Halmahera Sea has salinity values during a strong La Nina phase ranging from 33.6 to 34 PSU, compared to normal conditions where salinity values range from 33.7 to 34.1 PSU, resulting in a decrease of 0.1 psu. Salinity values in the southern part of the Halmahera Sea during a strong La Nina phase range from 33.6 to 34.4 PSU, compared to normal conditions with a range of 33.8 to 34.1 PSU, indicating an increase in salinity values of 0.2 PSU during a strong La Nina phase.

4. Conclusion

Sea surface temperature in most of the Halmahera Sea region tends to decrease during strong El Nino events, reaching 27.1°C, and increase during strong La Nina events, reaching 29.52°C. In contrast, weak La Nina events reach 28.07°C. Salinity content increases during strong El Nino events, with a salinity value of 34.1 PSU. Chlorophyll- α content in the Halmahera Sea region shows an increase during strong El Nino events in most areas, with an increase of up to 0.70 mg/m³, and a decrease during strong La Nina events in most areas, reaching a decrease of 0.12 mg/m³. Upwelling intensity increases during strong El Nino events, with sea surface temperature at 27.1°C and chlorophyll- α content of 0.70 mg/m³. During strong La Nina events, the Halmahera Sea experiences an increase in sea surface temperature and a decrease in chlorophyll- α content compared to its normal conditions, but it maintains upwelling intensity. Sea surface temperature in the upwelling area ranges from 29.52°C, with chlorophyll- α content around 0.12 mg/m³, indicating weak upwelling. During weak El Nino events, the intensity tends to decrease compared to strong El Nino events, with sea surface temperature at 28.07 and chlorophyll- α content at 0.40 mg/m³, categorizing it as weak upwelling. In the case of weak La Nina events, sea surface temperature is around 29.04, with chlorophyll- α content at 0.30 mg/m³, indicating weak upwelling intensity.

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