The relationship between oceanographic factors and the ENSO period on weather in Maluku

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Abstract. The surrounding waters strongly influence the waters of North Maluku. These waters are the entrance gate for ARLINDO, which is directly related to the Pacific Ocean. To produce scientific knowledge, our study aims to determine the influence of oceanographic factors on the distribution of sea surface temperatures (SST) and wind pattern, which affects the rainfall throughout the west monsoon and transitional seasons in the Indonesian region literacy. We used data from ERDDAP, where SST data was processed using Ocean Data View and wind data using WRPLOT. The SST of North Maluku waters during October 2020-April 2021 ranges from 29.1°C-29.8°C, with the highest sea surface temperature, was seen during November-December 2020 and April 2021. The result demonstrates the highest rainfall data was in February 2021 and the dominant winds come from north and west. These winds bring water vapor particles that become convective clouds that increase rainfall in Indonesia, especially in the eastern region. Meanwhile, SST originating from the Pacific Ocean moved due to the Walker Circulation from the east. This further caused the SST from the Pacific Ocean that brought a warm water move towards Indonesian waters.

Keywords: arlindo, La Nina, rainfall, sea surface temperature, wind circulation

1. Introduction
El Nino Southern Oscillation (ENSO) or El Nino that occurs in the Pacific Ocean is a phenomenon of shift or oscillation of warm water pools from the Indonesian territory. In this case, word "Western pacific is a more common scientific term than "Indonesia territory" to the east towards the Central Pacific due to the interaction of the ocean and the atmosphere [1]. ENSO, which forms in the Equatorial Pacific, has a warm El Nino phase, and its opposite, a cold La Nina phase. Which occur alternately every 2 to 7 years [2]. This oscillation phenomenon causes cloud accumulation away from Indonesia in June-November. ENSO then has a role in climate variability and rainfall, distributed in various regions in Indonesia, especially eastern Indonesia [3]. La Nina is one of the phases of ENSO that occurs due to an increase in the intensity of the trade wind speed that moves from the east Pacific towards the territory of Indonesia. Due to an increase in the intensity of the trade wind speed, this increases the movement of surface currents and the buildup of seawater masses in the territory of Indonesia, so that the sea surface temperature in Indonesia experiences an increase in temperature (warm). The La Nina phase itself is associated with the rainy season in Indonesia due to the convergence of evaporation which causes the accumulation of water masses in the air [4]. From 1990 to 2020, El Nino followed by the strongest La
Nina occurred in 1997-1998 [5] and 2015-2016. These two periods of the year have been named the worst drought years for Indonesia in the 20th and early 21st centuries [2].

El Nino from ENSO activity that occurs between July and November with warm sea surface temperatures in eastern Pacific region is a month with many occurrences of tropical cyclone phenomena [6]. The higher sea surface temperature, characterized by temperatures exceeding 26.5 C, and more water evaporation in the sea will provide energy in forming a tropical cyclone. Since the intensity of a tropical cyclone and its lifetime are closely related to the presence of ENSO activity, therefore a cyclone can be formed [4]. Basically, cyclones can occur in any month, but 2005 to 2015 was the year with the strongest cyclones recorded during the 1955 to 2015 period [6]. Previous studies have investigated the impact of high precipitation and strong winds [7]. The existence of tropical cyclones can be connected with global climate change because this phenomenon impacts the warming earth and an increase in the volume of precipitation that occurs on a regional scale [7]. Specific impacts that will be felt in the territory of Indonesia due to tropical cyclone phenomena include heavy rain, high waves, and strong winds [7]. Examples of areas that are most affected by these impacts are coastal and land areas. In addition to the negative impacts, tropical cyclones also have several positive impacts, such as increased fertility in the waters due to upwelling [8].

This study aims to know the impact of ENSO phenomenon and tropical cyclones on the weather conditions of Maluku. Based on some local reports [20], this area is experiencing high rainfall intensity than one area that is very closely related to the impact of the ENSO oceanographic phenomenon that occurs periodically because the region is very close to the Nino Index Region. The selection of the data period is based on the fact that the time interval of the study is alleged to have a significant impact on rainfall patterns, so it is necessary to prove each temporal parameter that causes rainfall intensity. The high intensity of rain that intersects with the impact of La Nina ENSO also occurred at that time [21].

2. Materials and methods

2.1. Study sites

The study area for this research is the Maluku Islands which is represented by Maluku (6,294,600 ha) and North Maluku (3,198,200 ha) to see the rainfall intensity in Maluku area [9]. The research point in North Maluku has coordinates (-0.000764°; 127.879044°) and (-3.150720°; 129.086443°) in Maluku.

The eastern region of Indonesia in the area that is more affected by the annual El Nino Southern Oscillation (ENSO) phenomenon because the region is very close to the Nino Index Region for sea surface temperature (SST), which is used to map the circulation in the tropical Pacific based on the average SST anomaly that occurs in the Pacific Ocean. Precipitation is also influenced by the back and forth movement of monsoon winds blowing from the Australian region (southeast) in June to August (JJA) and from the Asian region (northwest) from December to February (DJF) [10, 11].

2.2. Methods

Sea surface temperature (SST) data were processed using Ocean Data View (ODV) software version 5.2.1. ODV is a software package for exploration, quality control, and graphical analysis of irregularly distributed profile data available over the internet and is also free. ODV is available for Windows PCs and SUN Solaris workstations [12]. ODV can predict empty data points to be the most actual data and produce fast gridding algorithms that allow color shadows or so-called contours on sections or surfaces [12]. SST data were obtained from the Environmental Research Division Data Access Program (ERDDAP) with the NOAA ERSSTv5 dataset (in situ only), 2°, Global, Monthly, 1854-present, Lon+/-180.

Wind data was processed using the Wind Rose Plot for Meteorological Data (WRPLOT) software. WRPLOT is a Windows-based program that can generate statistics and plots of wind roses (wind chakra) from various meteorological data formats [13]. They display the distribution of wind speed with color variations at each speed and period [13]. For wind data, we obtained data from the Environmental Research Division Data Access Program (ERDDAP), which was then processed with a spatial resolution
of 10 m and a temporal resolution of 3 hours. The data used is surface wind data, namely a 10m-wind vector. The coordinates input used in downloading wind data based on the research coordinates contained in the explanation of point 1.1.

![Study Sites of the research](image)

**Table 1. Parameters used in research.**

| No | Parameter | Source | Spatial Resolution | Temporal Resolution |
|----|-----------|--------|--------------------|---------------------|
| 1  | Wind      | Erddap | 0.0001 degree      | 3 hours             |
| 2  | SST       | Erddap | 8 Km               | 1 month             |

3. **Results**

Based on the study and the objectives of this research, oceanographic parameters have been visualized, which are the main factors that affect weather and rainfall intensity patterns in the research area. The two parameters are the pattern of wind movement and the distribution of sea surface temperature.

3.1. **Wind**

The wind in November blows from the west to the east with the dominant wind speed of 3.6–5.7 m/s based on the red palette that shows the wind speed interval scale next to the windrose. Then, the wind in December blows from the north and northwest towards the south and southeast with the dominant direction going to the south and the dominant wind speed is > 11.1 m/s, which is indicated by turquoise in the wind speed interval scale.

The wind in January blows from the northwest and north towards the southeast and south with the dominant direction towards the southeast. The dominant wind speed is > 11.1 m/s which is indicated by
Figure 2. Wind speed in (A) November 2020, (B) December 2020, (C) January 2021 (D) February 2021, (E) March 2021, (F) April 2021.
turquoise in the wind speed interval scale. The wind in February blows from the north and west towards the south and east with the dominant direction going to the south, and the dominant wind speed is > 11.1 m/s which is indicated by turquoise in the wind speed interval scale. The wind in March blows from the west, north and northeast towards the east, south, and southwest with the dominant direction going to the east and the dominant wind speed is 2.1–3.6 m/s which is marked in yellow on the wind speed interval scale. The wind in April blows from the southwest and southeast towards the northeast and northwest with the dominant direction going to the northeast and the dominant wind speed is > 11.1 m/s which is indicated by turquoise in the wind speed interval scale. The wind speed pattern may show an insignificant effect because the wind speed was still dominated by the influence of the monsoon pattern [22].

The wind that blows from the north and west due to the west monsoon, which blows from Asia to Australia, resulting in the wind direction from north to south. The west monsoon also brings convective clouds from Asia to Australia. The effects of the west monsoon impact Indonesia, such as higher rainfall in several areas, especially in eastern Indonesia [17]. Meanwhile, the sea surface temperature originating from the Pacific Ocean moved due to the Walker Circulation from the east, which caused the SST from the Pacific Ocean, which brought the warm water mass towards Indonesian waters. The mass of warm water can increase rainfall, especially in the eastern part of Indonesia, because the evaporation in these waters also increases. From these two parameters, it can be said that rainfall in Indonesia, especially in the eastern region, is increasing due to convective clouds moving from Asia and SST from the Pacific Ocean, which carries warm water masses [16-19].

In times of strong El Nino winds are known to contain little moisture and cause a decrease in rainfall during the El Nino phase. A study explains that ENSO does not affect the resultant wind direction. Still, in the weak phase of La Nina phenomenon, it is seen that there is a low-pressure center in northeastern Indonesia. The La Nina phenomenon, which causes positive anomalies, makes the air humidity high and supports cloud formation which has the potential to increase rainfall [14].

3.2. Sea surface temperature (SST)

The northern waters of Maluku are known to have hot waters because of the mixing of water masses in Indonesia with water masses in the Pacific Ocean which typically ranges between 27.5°C–30°C [15]. From October 2020 to April 2021, North Maluku waters range from 29.1°C-29.8°C, with the highest sea surface temperatures in November-December 2020 and April 2021(Figure 3B). While in Maluku waters from September 2021 to April 2021, the sea surface temperature is around 29°C-29.8°C, with the peak of warm waters in December 2020 (Figure 3C).

In the second transitional season (September–November 2020), it is known that the sea surface temperature is in the range of 29.5–29.8°C (Figure 3A). In this transitional season, the surface temperature increases compared to the eastern season due to the sun's movement towards the southern hemisphere, which makes the intensity of sunlight in Maluku waters increase [18]. In the western monsoon period (December 2020–February 2021), the sea surface temperature ranges from 29.2–29.8°C, there is no significant change, but there is a decrease in temperature from December to February (Figure 3D). This is due to increased precipitation which allows lower sea surface temperatures. During the transitional season I (February–May 2021, it is known that the sea surface temperature increased but not significantly at 29.4–29.8°C. This SST increased possibly due to the La Nina phenomenon, which would bring warm water masses from the equatorial Pacific Ocean. Under normal circumstances, the transitional season I (February–May 2021) towards the east monsoon, sea surface temperatures will decrease from before due to the movement of the sun towards the northern hemisphere [18].

From September 2020 to April 2021 as seen through the Ocean Nino Index (ONI), a La Nina anomaly peaked in November 2020 with an index of -1.3 and slowly decreased until April 2021. The index is known to be -0.7. La Nina can increase sea surface temperatures in Indonesia and cause water mass accumulation and warm surface water to be carried from the Pacific Ocean [15]. From the visualization (Figure 3), it can also be seen that the influence of the Walker Circulation from the east causes the water mass originating from the Pacific Ocean to move to the west. This mass of water is carried because the
wind pressure in Indonesian waters is lower than the Pacific Ocean so that the wind moves to the west carrying a mass of warm water, which causes the sea surface temperature in Indonesia to be warmer, especially in the eastern region [16-19].

Figure 3. Sea Surface Temperature in (A) October 2020, (B) November 2020, (C) December 2020, (D) January 2021, (E) February 2021, (F) March 2021, (G) April 2021.
There are two main oceanographic factors, specifically, the sea surface temperature, as shown in Figure 4, to determine rainfall intensity, namely, wind flow pattern and the distribution of SST pattern. The rainfall data (Figure 5) is graphed from secondary data from the CHRS Data Portal website. It is found that rainfall in Maluku has increased since October and peaked in February before finally decreasing rapidly again. This increased rainfall is due to the ENSO anomaly, namely La Nina, which causes high evaporation and precipitation. Warm sea surface temperatures will increase the occurrence of evaporation and then make precipitation also increase. The location of the Maluku region, which is at the equator, is also one of the reasons for the high sea surface temperature and high evaporation. The correlation between sea surface temperature and evaporation in the Maluku region seems to be in harmony. When the temperature warms, evaporation increases, and when the temperature decreases, evaporation decreases, replaced by precipitation in the previous month's evaporation results. As previously explained, monsoon winds affect sea surface temperature and rainfall in Indonesia. SST increased during the transitional season II to the west season, causing increased evaporation assisted by sunlight and increased rainfall, which peaked in February [17]. The westerly monsoon that blows from the north and west to the south and east will carry warmer water masses from Asia to Australia. This will increase SST and evaporation, which causes high rainfall this season. This increased evaporation is also due to the sun's location in the southern part of the earth so that these waters are exposed to a lot of solar intensity [18].
4. Conclusion
Our research shows an influence of oceanographic factors on the distribution of sea surface temperature and wind movement patterns related to the period of the ENSO phenomenon and tropical cyclone phenomena on the weather conditions in Maluku. The wind that blows from the north and west due to the west monsoon, which blows from Asia to Australia, resulting in the wind direction from north to south. The west monsoon also brings convective clouds from Asia to Australia. The effects of the west monsoon impact Indonesia, such as high rainfall in several areas, especially in eastern Indonesia. Meanwhile, the sea surface temperature originating from the Pacific Ocean moved due to the Walker Circulation from the east, which caused the SST from the Pacific Ocean, which brought the warm water mass towards Indonesian waters. The mass of warm water can increase high rainfall, especially in the eastern part of Indonesia, because the evaporation in these waters also increases. From these two parameters, it can be said that rainfall in the Indonesian region, especially in the eastern region, increases due to convective clouds moving from Asia and SST from the Pacific Ocean, which carries warm water masses. In times of strong El Nino winds are known to contain little moisture and cause a decrease in rainfall during the El Nino phase. A study explains that ENSO does not affect the resultant wind direction. Still, in the weak phase of La Nina phenomenon, it is seen that there is a low-pressure center in northeast Indonesia. The La Nina phenomenon, which causes positive anomalies, makes the air humidity high and supports cloud growth, which can increase rainfall.

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