Variability of surface wind in Banda Sea and its correlation with El Niño and Southern Oscillation

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Abstract. Variability of surface winds in the Banda Sea and its correlation to El Niño and Southern Oscillation (ENSO) have been clearly demonstrated using the European Center for Medium-Range Weather Forecasts (ECMWF) reanalysis data. Surface winds in the Banda Sea are affected by monsoons. When the northwest monsoon, the wind comes from the north and west to the southeast, while the southeast monsoon, the wind comes from the southeast to the northwest. ENSO changes the direction and speed of the wind during the west season, whereas it only changes the speed during the east season.

1. Introduction

The wind is one of the climate elements that have an important role in the interaction between the sea and the atmosphere and is also the main energy source for the dynamics of marine waters, especially in the surface layer. Energy transfer from surface winds to the ocean will cause ocean waves and sea surface currents [1-4].

Scientifically the Banda Sea (BS) is part of the Benua Maritim Indonesia (BMI) which is the crossing point of the upper-layer current system as a branch of the global thermal circulation (known as Indonesian Throughflow, ITF) from the Pacific Ocean to the Indian Ocean. The dynamics of the marine ecosystem, the interaction of the ocean-atmosphere, and the variability of the marine climate in the Indo-Pacific are strongly influenced by the strength of these currents [5-8] (Figure 1).

BS upper layer dynamics and variability of the seasonal scale are influenced by the monsoon winds which cause convergence and diverging of the upward flow which changes seasonally associated with the formation of eddies and upwelling/downwelling [9-11]. Meanwhile, the inter-year marine time scale variability in the Banda Sea is also influenced by the El Nino Southern Oscillation (ENSO) climate variability anomaly in the Pacific Ocean and the Indian Mode Dipole (IOD) [9] in the Indian Ocean, as well as on the Madden Julian Oscillation (MJO) international time scale through Indonesian territory [12].

Based on this, research on surface wind circulation over the Banda Sea is important in order to support research programs regarding the interaction process between the sea and the atmosphere. This study aims to study and understand the characteristics and variability of monthly and seasonal surface winds in the Banda Sea, as well as their relationship with ENSO. It is important to do this in order to support previous research programs in the Banda Sea and aims to study and understand more deeply the characteristics and variability of the Banda Sea waters.
Figure 1. A Schematic flow of the Indonesian throughflow from the Pacific to the Indian Oceans through the interior Indonesian Seas. A deep Banda Sea (rectangle) is a confluence region of different Pacific water origins [8].

2. Materials and methods
2.1 Study area and data
The study area was located in the Banda Sea (Figure 1). The data used in this study are data with a monthly temporal resolution for the direction and surface wind speed of 10m with a time span of 1979-2018 obtained from the European Center Medium Range Weather Forecast (ECMWF) with spatial resolution 0.125°x 0.125° and ENSO Index data. Sea surface temperature anomaly data in nino 3.4 for the period 2008-2011 from the NOAA-Climate Prediction Center. Data processing and analysis were carried out at the Pusat Pengembangan Infrastruktur Informasi Geospatial (PPIIG), Pattimura University, Ambon.

2.2 Data processing and analysis
ECMWF wind data is processed using the average method so that monthly and seasonal averages are obtained for 40 years. The method used in this research is descriptive analysis, which provides an overview of the general pattern of surface wind circulation based on the results of data processing. Furthermore, the ENSO effect was analyzed on the surface current circulation patterns in the Banda Sea.

3. Results and discussion
3.1 Monthly Surface Wind Circulation Pattern in Banda Sea
The surface wind circulation pattern over the Banda Sea waters is a monthly average influenced by the monsoon winds, as shown in Figure 2. During the Northwest Monsoon (December to March) the winds over the Banda Sea waters generally come from two different sources. The first source from the north is from the Maluku Sea and the Seram Sea which passes through the islands of Buru and Seram to the Banda Sea, and the second source from the west is from the island of Sulawesi and the Flores Sea towards the Banda Sea. The winds from these two different directions combine over the Banda Sea and move to the southeast. The average surface wind speed in December was 3.68 ms⁻¹, increased in January (4.76 ms⁻¹), and continued to increase in February (4.82 ms⁻¹), but there was a decrease in speed in March (3.83 ms⁻¹). In April there was a turn in the wind direction in April. The
wind comes from the southeast and when it passes through the Banda Sea it is divided into two parts, namely in the eastern part of the Banda Sea the wind turns east towards Papua, while the central and western parts of the Banda Sea move to the northwest with an average speed of 3.60 $\text{ms}^{-1}$.

**Figure 2.** Average monthly surface wind circulation patterns in the Banda Sea

During the Southeast Monsoon (May to October), the wind blowing over the Banda Sea shows the same pattern, namely from the southeast to the northwest. The average surface wind speed increased respectively for May to July, May by 5.04 $\text{ms}^{-1}$, June (6.07 $\text{ms}^{-1}$), and July (6.40 $\text{ms}^{-1}$). While August to October there was a decrease respectively in the average surface wind speed for August 6.18 $\text{ms}^{-1}$, September (5.06 $\text{ms}^{-1}$), and October (3.83 $\text{ms}^{-1}$). Meanwhile, in November, there was a change in the surface wind circulation pattern where the wind blew from the southeast to the right (to the north) when passing through the northern part of the Banda Sea, and then again to the right (to the east) when it was over the islands of Buru and Seram, with The average wind speed has decreased significantly when compared to the other months, which is 2.68 $\text{ms}^{-1}$.

### 3.2 Seasonal Surface Wind Circulation Patterns in the Banda Sea

There is a clear seasonal variation in the direction and average surface wind speed in the Banda Sea (Figure 3). The West Season, namely in December-January-February (DJF), the wind comes from two different sources, namely the first source from the Maluku Sea and the second source from the Flores Sea towards the Banda Sea. The winds from these two different sources will meet in the Banda Sea and move towards the southeast with an average speed of 4.42 $\text{ms}^{-1}$. In the western monsoon (DJF) the sun is in the Southern Hemisphere (BBS) and receives more solar heat than the Northern Earth (BBU). It resulted in the center of high pressure above the Asian continent and the center of low pressure above the Australian continent. In this condition, the wind blows from the northeast, and when it passes through
Indonesia this wind is deflected due to the influence of the earth's rotation and becomes a northwest wind in Indonesian territory and blows southeast towards the center of low pressure on the Australian continent [1]. The Transitional Season I, namely in March - April - May (MAM), the surface winds blow from the southeast partially to the northwest and partly to the north with an average speed of 5.15 m\(s^{-1}\).

East monsoon, which is June-July-August (JJA) shows an increase in southeast wind speed towards the northwest with an average speed of 6.22 m\(s^{-1}\). In the eastern monsoon (JJA) when there is winter on Earth. South (BBS), the sun is at 23.5 ° N. The center of low pressure is on the Asian continent while the center of high pressure is on the Australian continent. The wind blows from the continent of Australia and then passes through the Indonesian territory, the wind turns from the southwest towards the northeast through the western part of Indonesia towards the center of low pressure in the northern region of the Asian continent [1]. The second transitional season, namely in September-October-November (SON), the wind blows from the southeast to the northwest (the same as in the east season) but with a smaller average speed of 3.91 m\(s^{-1}\).

### 3.3 Variability of surface winds in the Banda Sea during the ENSO Phase from 2008 to 2011

The seasonal surface wind circulation patterns in the Banda Sea in the three ENSO phases are shown in Figure 5. There are clear seasonal variations in the direction and speed of surface winds in the Banda Sea waters for the three ENSO phases, namely the ENSO Normal phase (June 2008 to May 2009), El Niño (June 2009 to May 2010), and La Niña (June 2010 to May 2011).

In the West Season (DJF) during the Normal ENSO phase, the direction of the surface winds in the Banda Sea is the same as the direction of the seasonal average surface winds in the Banda Sea from 1979 to 2018 (Figure 4 Part A), but different during the El Niño phase (Figure 4 Part B) and La Niña (Figure 4 Part C). In the West season during the Normal ENSO phase, the wind blows from two different directions, namely from the northwest (Maluku Sea) and from the west (Sulawesi Island) to the Banda Sea and moves to the southeast with an average speed of 4.81 m\(s^{-1}\), while during the El Niño phase the wind blows only from one direction, namely from the west (the Flores Sea and Sulawesi Island) which then turns to the southeast when passing through the Central Banda Sea with an average speed of 4.55 m\(s^{-1}\).
ms\(^{-1}\) smaller than the average speed. Average during the Normal ENSO phase. Meanwhile, during the La Niña phase the wind also only blows from one direction from the northwest (Maluku Sea) to the southeast with an average speed of 4.53 ms\(^{-1}\), which is smaller than the average velocity during the ENSO Normal phase and the El Niño phase.

![Figure 4. Average seasonal surface wind circulation patterns during the ENSO phase from 2008 to 2011 in the Banda Sea](image)

The direction of the surface winds in the Banda Sea in the East monsoon (JJA) for the three ENSO phases (ENSO Normal, El Niño, and La Niña) is the same as the direction of the seasonal average surface winds in the Banda Sea in 1979-2018 (Figure 4 Part D, E, and F). The wind direction comes from the southeast to the northwest. There is a difference in the average east monsoon surface wind speed between the three ENSO phases, namely when ENSO Normal is 6.40 ms\(^{-1}\), increases during El Niño by 6.71 ms\(^{-1}\), and weakens during La Niña by 5.93 ms\(^{-1}\). The increase in wind speed during the El Niño phase is due to the weakening of the trade winds in the equatorial region of the Pacific Ocean which causes cooling in the area around the western Pacific Ocean which causes high pressure which in turn increases wind speed during the East monsoon. Meanwhile, when La Niña occurs, there is an increase in trade wind speed in the equatorial Pacific Ocean which will cause warming in the area around the western Pacific Ocean which will cause low pressure in the region which will ultimately reduce surface wind speed during the East monsoon.

4. **Conclusion**

Surface winds in the Banda Sea are affected by monsoon winds. During the northwest monsoon (December to March), the wind direction towards the Banda Sea comes from north and west, towards the southeast. Meanwhile, during the southeast monsoon (May to October), the wind blows from the southeast to the northwest. West monsoon (DJF), wind direction from two sources, namely northwest and west, then merges and heads southeast with an average speed of 4.42 ms\(^{-1}\). The Transitional Season I (MAM) winds from the southeast and is divided, partly to the north and partly to the northwest with an average speed of 5.15 ms\(^{-1}\). East Season (JJA) and Transition Season II (SON), the wind direction comes from the southeast to the northwest, with an average speed of 6.22 ms\(^{-1}\) and 3.91 ms\(^{-1}\), respectively. ENSO changes the direction and speed of surface winds during the West monsoon (DJF) in the Banda Sea. During El Niño, the wind direction only comes from the west with an average speed of 4.55 ms\(^{-1}\), and when La Niña only comes from the northwest with an average speed of 4.53 ms\(^{-1}\). Whereas in the east monsoon (JJA), ENSO does not change the direction of the wind, that is, it still
comes from the southeast to the northwest, but changes the average surface wind speed in the Banda Sea during ENSO Normal (4.53 m s\(^{-1}\)), El Niño respectively. (6.71 m s\(^{-1}\)), and La Niña (5.93 m s\(^{-1}\)).

**Acknowledgement**

This study was supported by research facilities from PPIIG Pattimura University. We also thank the Europian Center Medium Range Weather Forecast (ECMWF) and NOAA-Climate Prediction Center, for providing the data.

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