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OCEAN CURRENT PATTERN AND WATER MASS CHARACTERISTIC IN THE RESPONSE OF CLIMATE EVENTS ON THE NORTHWESTERN SUMATRA WATER

POLA ARUS LAUT DAN KARAKTERISTIK MASSA AIR SEBAGAI RESPON TERHADAP FENOMENA IKLIM DI PERAIRAN BARAT LAUT SUMATERA

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Abstrak

El Niño lemah dan *Indian Ocean Dipole* positif yang diikuti *La Niña* moderat dan *Indian Ocean Dipole* negatif yang terjadi pada tahun 2017 memberikan pengaruh terhadap kondisi perairan barat laut Sumatera. Penelitian untuk menganalisis hal tersebut dilakukan menggunakan kapal riset Baruna Jaya VIII pada pelayaran riset Ekspedisi Widya Nusantara (EWIN) Desember 2017. Pelayaran ini bertujuan untuk menganalisis pengaruh perubahan iklim terhadap pola arus laut dan karakteristik massa air. Data hidrografi dari pelayaran tersebut didukung oleh data satelit suhu permukaan laut (SPL), data anomali angin yang bersumber dari *The European Centre for Medium-Range Weather Forecasts* (ECMWF), dan data arus yang bersumber dari *Ocean Surface Current Analysis Real-Time* (OSCAR) *Physical Oceanography Distributed Active Center* (PODAAC). Hasil penelitian menunjukkan adanya SPL hangat di timur Samudera Hindia termasuk di dalamnya perairan barat Sumatera saat fenomena La Nina moderat diikuti IOD negatif. Data parameter fisis berupa suhu dan salinitas menunjukkan bahwa massa air di lapisan atas dan tengah perairan barat laut Sumatera berasal dari Samudera Hindia. Data arus mendukung hal tersebut dengan menunjukkan bahwa arus pada bulan Desember bergerak dari barat menuju timur dan diperkuat pula oleh fenomena IOD yang menyebabkan anomali angin dari barat ke timur sehingga massa air dari Samudera Hindia dapat masuk ke perairan barat laut Sumatera.

Kata Kunci: *Perairan Barat Laut Sumatera, Iklim, Massa Air, Arus, Musim*

Abstract

A weak El Niño and a positive Indian Ocean Dipole followed by a moderate La Niña and a negative Indian Ocean Dipole that occurred in 2017 had an impact on the condition of the waters of northwest Sumatra. Research to analyze this was carried out using the Baruna Jaya VIII research vessel on the Widya Nusantara Expedition (EWIN) research cruise in December 2017. This voyage aims to analyze the effect of climate change on ocean current patterns and the characteristics of water masses.

Hydrographic data from the voyage are supported by satellite sea surface temperature (SST) data, wind anomaly data sourced from The European Center for Medium-Range Weather Forecasts (ECMWF), and current data sourced from Ocean Surface Current Analysis Real-Time (OSCAR)) Physical Oceanography Distributed Active Center (PODAAC). The results showed that there was a warm SST in the eastern Indian Ocean including the western waters of Sumatra when the La Nina phenomenon was moderate followed by a negative IOD. Physical parameter data in the form of temperature and salinity show that the mass of water in the upper and middle layers of the waters of northwest Sumatra originates from the Indian Ocean. Current data supports this by showing that currents in December move from west to east and are also reinforced by the IOD phenomenon which causes wind anomalies from west to east so that water masses from the Indian Ocean can enter the waters northwest of Sumatra.

INTRODUCTION

El Niño Southern Oscillation (ENSO) is a natural phenomenon involving fluctuation of ocean temperatures in the central and eastern equatorial Pacific Ocean, coupled with changes in the atmosphere (Nurutami *et al*., 2016). El Nino and La Nina are the extreme phases of ENSO. El Nino occurs when warm waters accumulated in the central and eastern equatorial Pacific Ocean accompanied by the weakening of the east wind (Wilopo, 2005). As a result, tropical rain that usually falls in Indonesia shifted to the east. La Nina conditions occur when cold waters are accumulated in the central and eastern equatorial Pacific Ocean along with strengthening winds above the central Pacific Ocean (Wilopo, 2005). El Nino and La Nina affect the global climate, including Indonesia. El Nino or La Nina can give different impacts on different areas.

As well as the Pacific Ocean, ocean-atmosphere interaction also occurs in the region of Indian Ocean that form two poles of sea surface temperature anomalies between West Java and South Sumatra with the waters of Africa called the Indian Ocean Dipole (IOD). IOD consists of positive IOD (pIOD) and negative IOD (nIOD). During negative IOD, low SST is found in the western Indian Ocean and high SST is in western Sumatra waters. As a result, the wind blows eastward lead to an increase in the intensity of rainfall in Indonesia and drought in Africa (Iskandar, 2014).

Research related to the physical oceanography characteristics had been conducted in previous studies such as analyzing sea surface temperature, sea level, and wind using satellite data (Wilopo, 2005) and field measurements in Simeulue Island (Surinati, 2009). While water mass distributions play a role in many of today’s oceanographic problems, there is very few research directed at improving our knowledge of water mass distributions and their changes over time (Emery, 2001). Study related to the relationship between climate events with physical oceanography had been conducted by Bayhaqi *et al* (2018). Using the same method, this study aims to find out the relationship between climate events with sea conditions which focused on the area of the northwestern Sumatra. This area is one of the sea surface temperature anomaly pole in the Indian Ocean that triggered the Indian Ocean Dipole (Iskandar, 2014). The geographical location of northwestern Sumatra which is still part of the waters of Indian Ocean is influenced by Wyrtki Jets raised by monsoon (Wyrtki, 1961). The northwestern Sumatra is also located near two major oceans i.e. the Indian Ocean and the Andaman Sea. Then, the water masses in the surrounding northwestern Sumatra are simply sourced from both of these waters. Mixing of water masses produces a variety of oceanographic phenomena (Sugianto *et al*., 2007). West Sumatra waters are also very influential to climate change in the Indian Ocean (Iskandar, 2014) so that the study in the location of the research is needed to be done.

METHOD

Observation Data

Observation data are obtained from Ekspedisi Widya Nusantara (EWIN), conducted by Research Center for Oceanography (RCO), Indonesian Institute of Sciences (LIPI) on Desember 2017. The observation data consist of hydrography properties and ocean current data which are recorded by Conductivity Temperature Depth (CTD) and vessel mounted Acoustic Doppler Current Profiler (SADCP) respectively. While the CTD measures hydrography data at 16 stations, the ADCP records the velocity component of ocean current along the cruise track (see Figure 1).

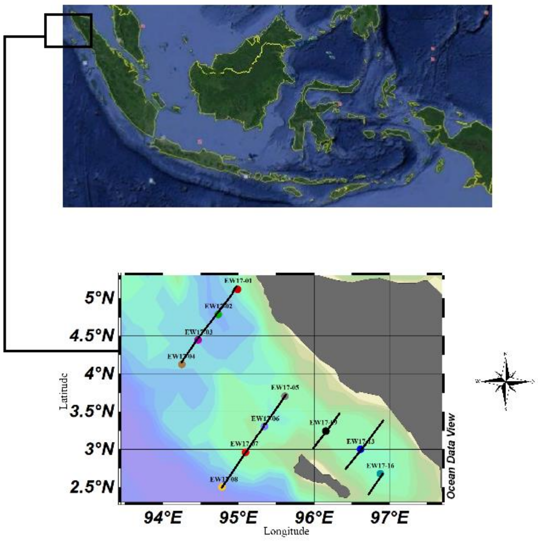


Figure 1. ADCP measuring stations on five sections (showed by black lines) and CTD measuring stations on three sections (showed by dots).

Satellite Data

Satellites are problem-solving solutions for studying ocean interactions with the atmosphere that play an important role for the earth, one of them is altimetry satellite (Handoko, 2004). Altimetry satellites monitor the topography and dynamics that occur at sea level continuously so that it can be used to determine the pattern of currents in Indonesian waters. Monthly SST data is taken from *Copernicus Marine Environment Monitoring Service* with the product in the form of *Global Analysis Forecast* PHY_001_024 and *Global Reanalysis Forecast* PHY_001_030. The current data is taken from the *Ocean Surface Current Analysis Real-Time* NOAA in 2017. Meanwhile the monthly wind data is sourced from the *European Centre for Medium-Range Weather Forecasts* from January 2008 until December 2017 with a temporal resolution of 0.75°. Dipole Mode Index (DMI) is the IOD index that calculated based on the average anomaly of SST on the Western Tropical Indian Ocean, WTIO (50° E - 70° E, 10° S - 10° N) and Southeastern Tropical Indian Ocean, SETIO (90° E - 110° E, 10° S - Equator) (Iskandar, 2014; Bayhaqi *et al*., 2018).

RESULTS AND DISCUSSION

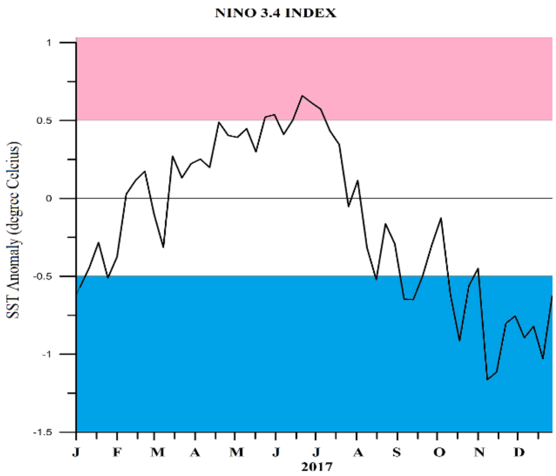
The Climate Phenomena in 2017

As the one of the polar anomalies in the Indian Ocean, the northwestern Sumatra waters are mainly influenced by Indian Ocean Dipole (IOD) (Iskandar, 2014) and El Niño Southern Oscillation (ENSO) (Saji, *et al*., 1999). This section explains the climate events on sampling year showing the time series of Nino 3.4 and Dipole Mode Index (Figure 2).

During 2017 the weak El Nino phenomenon occurred in the Pacific Ocean (Figure 2a) which followed by positive Indian Ocean Dipole (pIOD) in the Indian Ocean (Figure 2b). The phenomenon of El Nino occurred briefly started in May 2017 (index value of 0.522), peaked in June 2017 (index value of 0.659) and ended in July 2017 (index value of 0.573). While the positive IOD began in March 2017 (index value of 0.491), peaked in May 2017 (index value of 1.116), and ended in September 2017 (index value of 0.694). In addition, during 2017 there was moderate La Nina phenomenon in the Pacific Ocean (Figure 2a) followed by negative IOD in the Indian Ocean (Figure 2b). The moderate La Nina started in September 2017 (index value of 0.646), peaked on November 2017 (index value of 1.164), and ended on December 2017 (index value of 0.628). While negative IOD occurred shortly in December 2017 (index value of 0.628).

a)

Positive IOD +4 Negative IOD -4



Weak El Nino 0.5 until 1 Weak La Nina -0.5 until -1

Moderate El Nino 1 until 2 Moderate La Nina -1 until -2

Strong El Nino > 2 Strong La Nina < -2

b)

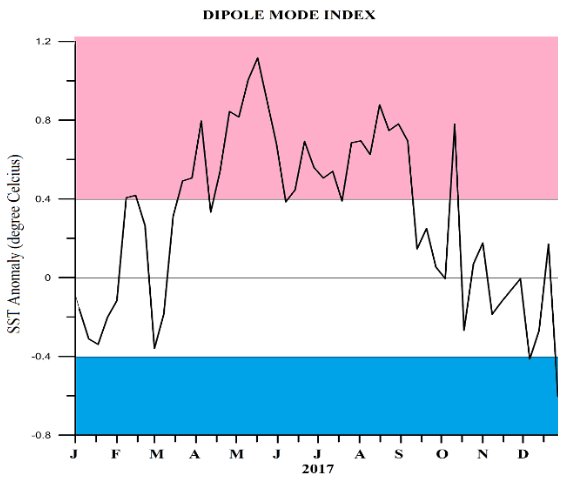


Figure 2. Time series of the index of Nino 3.4 (a) and Dipole Mode Index (b) from January to December 2017. The red curve shows El Nino or positive IOD while the blue curve shows La Nina or negative IOD.

Figure 3 shows the spatial and temporal SST anomalies in the southeast Indian Ocean including the Northwestern Sumatra. EWIN research cruise conducted when moderate La Nina phenomena occurred in the Pacific Ocean and the nIOD occurred in the Indian Ocean showed by warmer SST anomalies in the southeastern Indian Ocean. When nIOD occurs, warmer SST is observed at northwestern Sumatra. Along with that, wind along the equator leads to the east because west monsoon that moves eastward has a deeper thermocline in the southeast than in the western. In addition, the wind brings a high intensity of clouds toward Indonesia and eastern part of the Indian Ocean, this can lead to increased rainfall in Indonesia and drought in Africa (Vinayachandran *et al*., 2002; Iizuka *et al*., 2000).

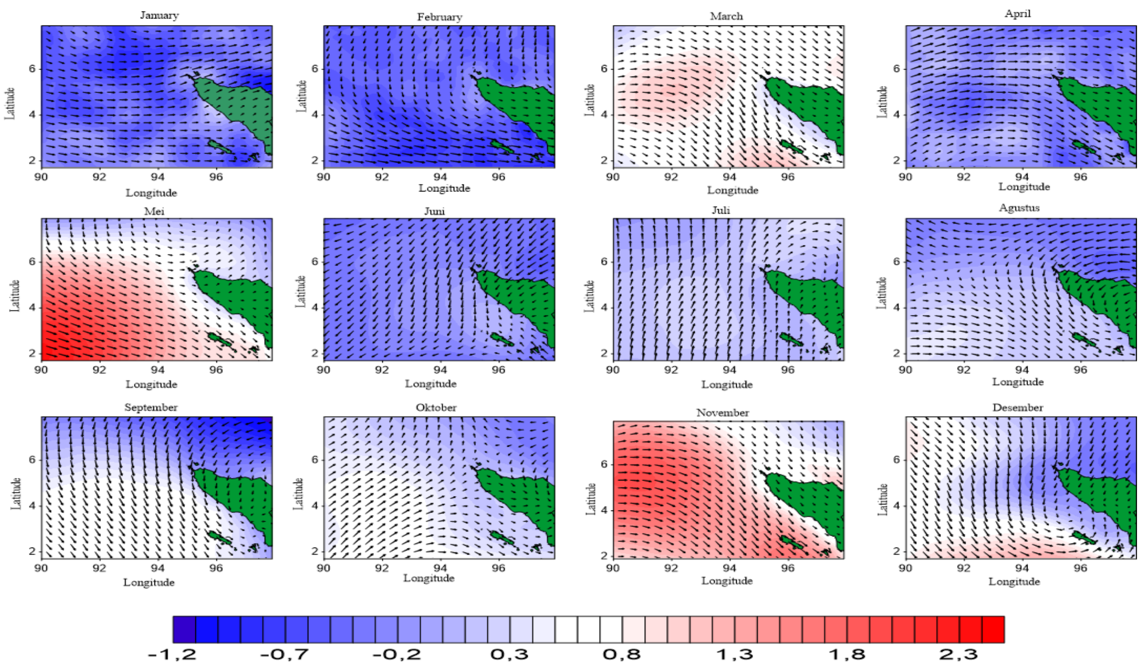


Figure 3. Spatial-temporal SST and wind anomalies on the northwestern Sumatra during January to December 2017.

Water Mass Characteristic

Figure 4 shows the T-S diagram of water mass observed during observations in December 2017. According to the table of temperature-salinity characteristics of the world's water mass (Emery, 2001), there are five types of water masses that observed in the area of research. On the surface of the water (depth of 0 – 500 m) Bengal Bay Water (25° C - 29° C, 28‰ – 35‰), Indian Equatorial Water (8° C - 23° C, 34.6‰ – 35‰), Indonesian Upper Water (8° C - 23° C, 34.4‰ – 35‰), and South Indian Central Water (8° C – 25° C, 34.6‰ – 35.8‰) was observed. The middle layer between 500-1500 m, there was a mass of water from the Red Sea-Persian Gulf Intermediate Water (5° C – 14° C, 34.8‰ – 35.4‰). The data of satellite and ADCP show that the mass of water that affects the northwestern Sumatra was derived from the Indian Ocean.

The Mass Spatial distribution of the observed water

From the T-S diagram of section 1,2 and 3 (Figure 5), it can be observed that the water mass on the surface (depth 0 – 500 m) is sourced from the Bengal Bay Water (25° C - 29° C, 28‰ – 35‰), Indian Equatorial Water (8° C - 23° C, 34.6‰ – 35‰), Indonesian Upper Water (8° C - 23° C, 34.4‰ – 35‰), and South Indian Central Water (8° C – 25° C, 34.6‰ – 35.8‰). The middle layer (500 – 1500m) is sourced from the Red Sea-Persian Gulf Intermediate Water (5° C – 14° C, 34.8‰ – 35.4‰). Thus, it can be concluded that the spatial distribution of water masses from the Indian Ocean is same.

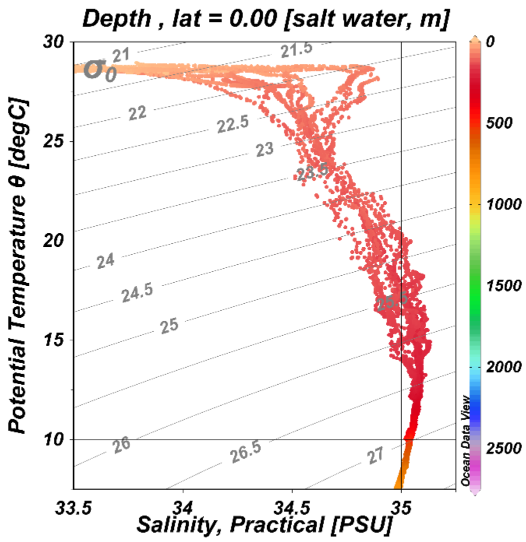


Figure 4. T-S diagram all CTD observation stations in November 2017.

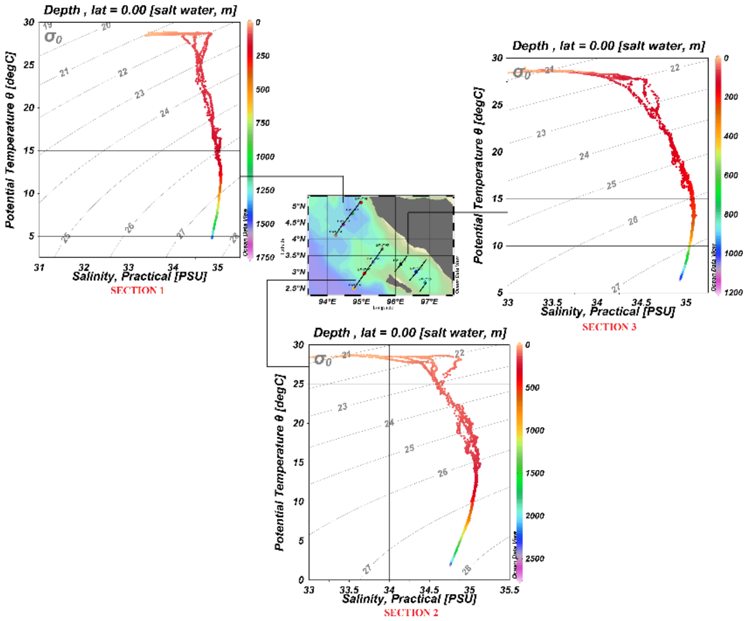


Figure 5. T-S diagram of water mass observed in the region of the Northwestern Sumatra**.**

Ocean Current Pattern

To determine the dynamics that affect the mass distribution of water during the observation period, it is necessary to analyze the direction and velocity of the currents on the research area using the ADCP (Figure 6).

Data research using ADCP consists of three sections: section 1, 2, and 3 as shown in Figure 1. Furthermore, section 3 is divided into three section again, so that all ADCP data research consists of five sections. In section 1 shown in Figure 6a, the current on the surface to a depth of 100 meters shows the dominance of the northwest direction with a maximum current velocity of 1.34 m/s and an average velocity of 0.55 m/s. While the current at a depth of more than 100 meters shows the dominance of the southwest direction with a maximum current velocity of 2.33 m/s and an average velocity of 0.23 m/s. In section 2 shown in Figure 6b, the current on the surface to a depth of 100 meters shows the dominance of the northwest direction with a maximum current velocity of 1.71 m/s and an average velocity of 0.68 m/s. While the current at a depth of more than 100 meters shows the dominance of the southwest direction with a maximum current velocity of 2 m/s and an average speed of 0.24 m/s. In section 3 shown in Figure 6c, the current on the surface to a depth of 100 meters shows the dominance of the northwest direction with a maximum current velocity of 0.98 m/s and an average velocity of 0.46 m/s. While the current at a depth of more than 100 meters shows the dominance of the northwest direction with a maximum current velocity of 2 m/s and an average velocity of 0.24 m/s. In section 4 shown in Figure 6d, the current on the surface to a depth of 100 meters shows the dominance of the northeast direction with a maximum current velocity of 0.82 m/s and an average velocity of 0.34 m/s. While the current at a depth of more than 100 meters shows the dominance of the northwest direction with a maximum current velocity of 1.99 m/s and an average velocity of 0.19 m/s. In section 5 shown in Figure 6e, the current on the surface to a depth of 100 meters shows the dominance of the northeast direction with a maximum current velocity of 0.86 m/s and an average velocity of 0.51 m/s. While the current at a depth of more than 100 meters shows the dominance of the northwest direction with a maximum current velocity of 1.17 m/s and an average velocity of 0.2 m/s.

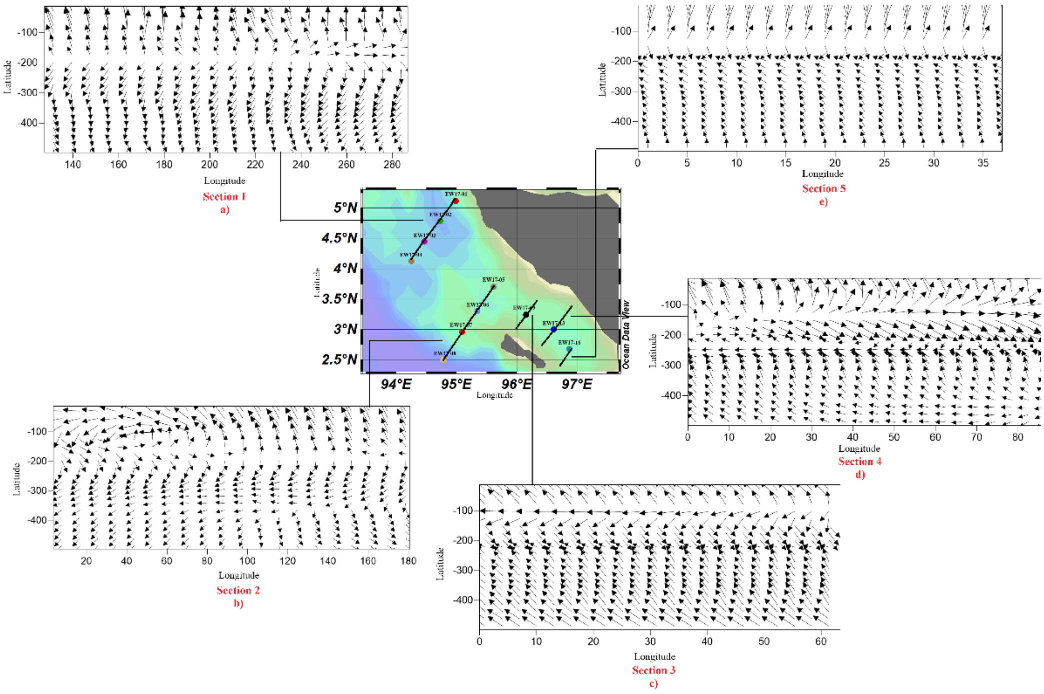


Figure 6. Zonal and meridional flow from the Northwestern Sumatra

ADCP current data and physical parameters were obtained when the northwest monsoon occurred so that the wind direction was dominated from west to east, moreover it coincided with the occurrence of La Nina which caused the wind to move from eastern to western and negative IOD which caused the wind to move from western to eastern. While based on the analysis, it is known that the five sections have a different direction. In section 1, 2, and 3 the surface currents mostly move towards the northwest, while in sections 4 and 5 the surface currents mostly move towards the northeast. The fifth section is located in the northwestern of the Sumatra mainland. Sections 1, 2 and 3 are located precisely in the northwest of Sumatra and meet directly with the open waters of the Indian Ocean, while sections 4 and 5 are located northwest of the Sumatra mainland but are flanked by the island of Simeulue. All currents in the fifth section are circulating from before meeting the land so that the currents in sections 1, 2, and 3 circulate to the northwest while the currents in sections 4 and 5 are flanked by two landforms circulating northeast.

There are several different directions between surface (0 – 100 m) and subsurface layer (more than 100 m). That condition is caused by the influence of wind forcing at the certain depth (Stewart, 2008).

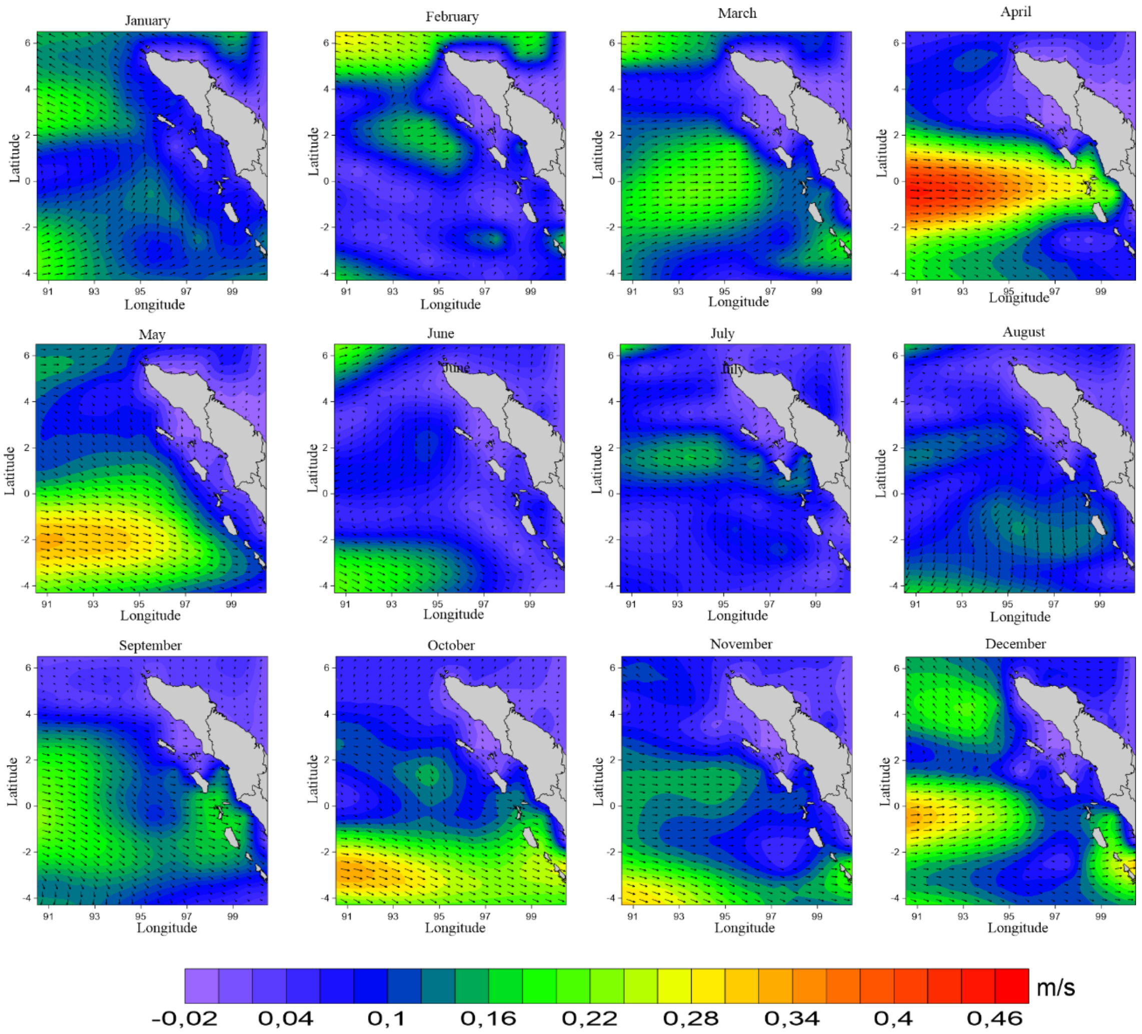


Figure 7. Surface current velocity and direction during 2017.

Based on satellite data, the currents on December 2017 moves towards Sumatra and then deflected to the northwest (Figure 7) which is in accordance with the results of the analysis of ADCP data that shows the current direction to the northwest (Figure 6). As part of the western season, surface currents during December 2017 at coordinates 1.5˚ N - 6˚ N and 93.5˚ E - 98˚ E mostly moved northwest. Maximum current velocity is 0.2 m/s, while the average velocity is 0.12 m/s. While the wider area includes a small part of the eastern Indian Ocean, most of the current moved northeast, northwest, and southeast. Maximum current velocity is 0.34 m/s, while the average velocity is 0.14 m/s.

The northwestern Sumatra is also affected by global climates such as ENSO and the Indian Ocean Dipole (Saji *et al.*, 1999). Based on the index of Nino 3.4 and Dipole Mode Index which had been discussed previously, there was a moderate La Nina phenomenon in September until December 2017 in the Pacific Ocean followed by short nIOD in December 2017 in the Indian Ocean that caused westward current on the northwestern Sumatra. The northwestern Sumatra is one of the pole of sea surface temperature anomalies. When nIOD occurs, the surface temperature of the northwestern Sumatra is warmer so that the wind moves the current towards the warmer region. This led to the existence of various water mass characteristics from the Indian Ocean in the northwestern Sumatra waters.

Based on Figure 7, the monsoon currents in the waters of northwestern Sumatra and surrounding areas are mostly eastward. This is due to its geographical location which is still part of the Indian Ocean. In the west and transitional seasons, the wind above the equator of the Indian Ocean is dominated by western winds which will generate equatorial currents, known as the Wyrtki Jets. Wyrtki Jets is a stream that moves to the east, after reaching the western waters of Sumatra or before meeting the land of Sumatra, the energy will be divided into three parts: turning to the Indian Ocean in the form of Rossby waves that propagate to west, propagating to north towards the Bay of Bengal, and heading to southeast along the waters of western of Sumatra and southern of Java (Mardiansyah and Iskandar, 2014).

CONCLUSION

In general, the ocean current pattern in the western waters of Sumatra in December 2017 shows the movement from west to east because it is influenced by the western monsoon and is strengthened by the negative IOD, although the currents at the research area moved in different directions i.e. northwest and northeast due to its geographical location close to the land so the current turned and continued its circulation to the northwestern and northeastern. Water masses that is known based on physical parameter data comes from the Indian ocean. That was caused by western monsoons that carried water masses from the Indian Ocean and were strengthened by negative IOD. Based on the research, it is necessary to study the response of other physical parameters to climate phenomena such as rainfall variability, upwelling-downwelling phenomena, divergent-convergent, eddy current, and oceanic front.

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