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ENSO impacts during west and east monsoon to the ocean current and water mass characteristics in the Makassar Strait

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Abstract. Ocean and atmospheric interactions are known by the presence of El-Nino Southern Oscillation (ENSO) in the Pacific Ocean, dipole mode in the Indian Ocean, and Indonesian-Throughflow (ITF). Those interactions have impacts to oceanographic conditions of Indonesian waters, especially Makassar Strait as main route of ITF which carries warm water masses to Indian Ocean due to the El-Nino and La-Nina as part of global scale oceanic belt. The purpose of this research is to understand the ENSO effect on spatio-temporal of current patterns and characteristics of water mass, namely temperature and salinity during west and east monsoon in the Makassar Strait. This study are using the ENSO index data from NOAA between year 2000-2015 and ¼ degrees resolution of temperature, salinity, and currents monthly model from Copernicus Marine Environment and Monitoring System (CMEMS) with focus in February and August 2010 and 2015 to represents respectively for west and east monsoon period during the ENSO year. The results showed that surface currents were stronger during La-Nina with speeds of 0.8 to 1.2 m/s compared to El-Nino event with speeds of 0.6-0.7 m/s and it is higher in east monsoon. During west monsoon the current leads to the east and reversely the current pattern changes to the west during east monsoon. The temperature and salinity when La-Nina events are about 1°C higher and 0.7 psu lower than El-Nino events. Based on the results, in general that the impacts of El-Nino an La-Nina events to the Makassar Strait are clearly shown during east monsoon.
Keywords: ENSO, monsoon, oceanographic conditions, CMEMS, Makassar Strait

1. Introduction

The interaction of ocean and atmospheric can be seen from the Indonesia's climate interaction with ENSO phenomenon in the Pacific Ocean, dipole mode in the Indian Ocean, and the Indonesia throughflow. The dynamics of the ocean and atmosphere in the relation with these large-scale phenomena begin with the formation of potential clouds, cyclones even El Niño Southern Oscillation (ENSO) and Indonesia throughflow (ITF) [1]. The condition of Indonesian Oceanography are mostly affected by monsoon winds and Indonesia throughflow. Monsoon winds, which furthermore cause the monsoon flow caused by different pressure between Asia Tenggara and Australia. West monsoon there are in December-February, East monsoon in June-August, and between of them called transition. Indonesia throughflow is current of warm water mass from Pacific Ocean to Indian Ocean through Indonesian's waters that caused by the different of sea surface height between of these ocean [2]. Characteristics of an ocean can be known both through physical properties and the chemical properties of water such as temperature, salinity, conductivity, dissolved oxygen, and nutrient content. Among

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these variables, temperature and salinity have an important role to reflecting the sea water mass conditions [3].

Based on that cases, the East Indonesian waters conditions is very interesting to research because the East Indonesian waters are located at the intersection of the water mass movement that come through the Indonesian Monsoonflow and the Indonesian Throughflow. The Makassar Strait is the main traffic lane through of Arlindo, so in this research just limited to the Makassar Strait area to know the effect of strong ENSO that occur during 2010 (La-Nina) and 2015 (El-Nino) to the ocean current patterns and water mass characteristics temperature and salinity.

1.1. El Niño Southern Oscillation (ENSO)

ENSO is a phenomenon of atmospheric oceanic interactions that centered in the Pacific Ocean equatorial [4]. The oscillations of this phenomenon carry two phenomena namely El Niño and La Niña, are warm and cold phases of the Pacific equatorial region. Normally there is a warm pool in north of the Papua island which is a gathering place for surface currents from global oceanic belt. This warm pool also is a circulation place of Walker where there is an air lift (convection center). However, during El Niño, there is a movement warm pool area to the east of the Pacific equator and leaving the subsidence area (contrast to the convection area) in north of Irian. The warm pool area to be cools and with Indonesian throughflow brings the cold currents to the Indonesian waters which also causes drought due to obstruction of evaporation due to the cold of the sea. The contrary indication when La Niña period, occurs more warming in the warm pool area. The accumulation of water masses in the warm pool area causes Indonesian Throughflow are strength [1].

The accumulation in warm pool causes sea surface height in the warm pool area rather than Indian Ocean. The warm accumulation on surface are brings implications for the warm accumulation to the subsurface which thickens the thermocline layer in the warm pool area. When El Niño, occurs the warm water mass movement to the east on the surface and below, so there is a change in the thinning thermocline layer in the western Pacific Ocean and the warm water mass flowing to east. The main cause of the warm water mass flow to the east is currently unknown but the possibility is due to differences in temperature and energy gradients due to energy accumulation in the warm pool area compared to the central Pacific [1].

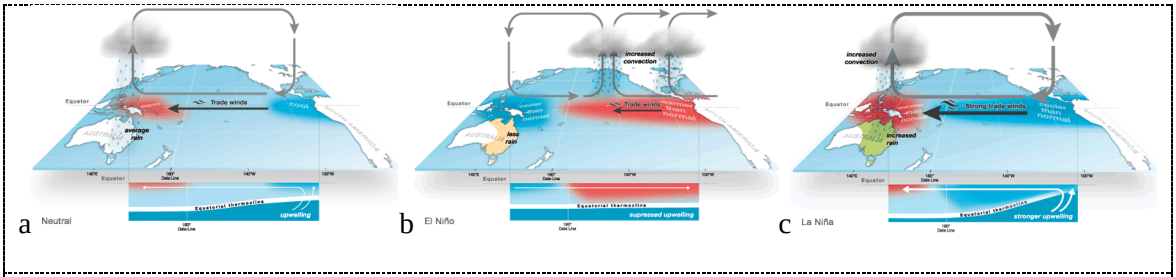


Figure 1. Global climate phenomenon (a) normally, (b) El-Nino, (c) La-Nina (*Source:* Bureau of Meteorology)

1.2. Oceanic Nino Index (ONI)

ONI is the main parameter used by NOAA to monitor, assess and predict ENSO (El Nino and La Nina), a phenomenon of climate anomalies in a global scale. This ONI is based on the changes of SST value from the average Nino 3.4 area. Taken an average of three months. El Niño is marked with a positive ONI greater than or equal to + 0.5ºC while La Niña is marked with a negative ONI less than or equal to -0.5ºC. ONI graph National Oceanic and Atmospheric Administration (NOAA) shown that from 2000 until 2015 have been occurs many times El Nino and La Nina phenomenon, but very strong occurs on 2010 and 2015. La Nina 2010 phenomenon are known with the NINO 3.4 SST Index value highest -1.6°C. While the El Nino 2015 very strong the highest NINO 3.4 SST Index is +2.6°C.

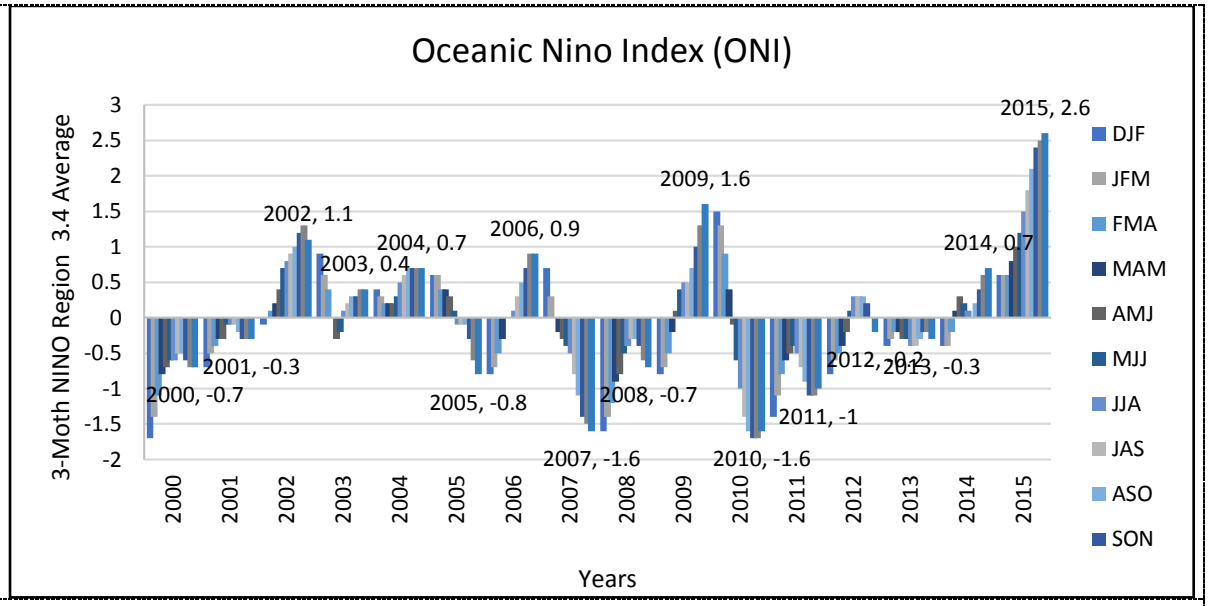


Figure 2. Graph of Oceanic Nino Index (ONI), 2000-2015 (*Source:* NOAA Climate Prediction Center).

2. Methods

The research area is Makassar Strait. The data used in this study include the ONI (Oceanic Nino Index) data 2000-2015 from NOAA http://origin.cpc.ncep.noaa.gov between year 2000-2015 to see the El Nino and La Nina occurrence periods. Temperature, salinity, and currents monthly model ¼ degrees spatial resolution from Copernicus Marine Environment and Monitoring System (CMEMS) http://marine.copernicus.eu. with focus in February and August 2010 and 2015 to represents respectively for west and east monsoon period during the ENSO year. The data thus processing to be spatial and temporal distribution and next to analyzing the conducted between the distribution of temperature, salinity and current patterns when the El Nino and La Nina period.

3. Results and discussions

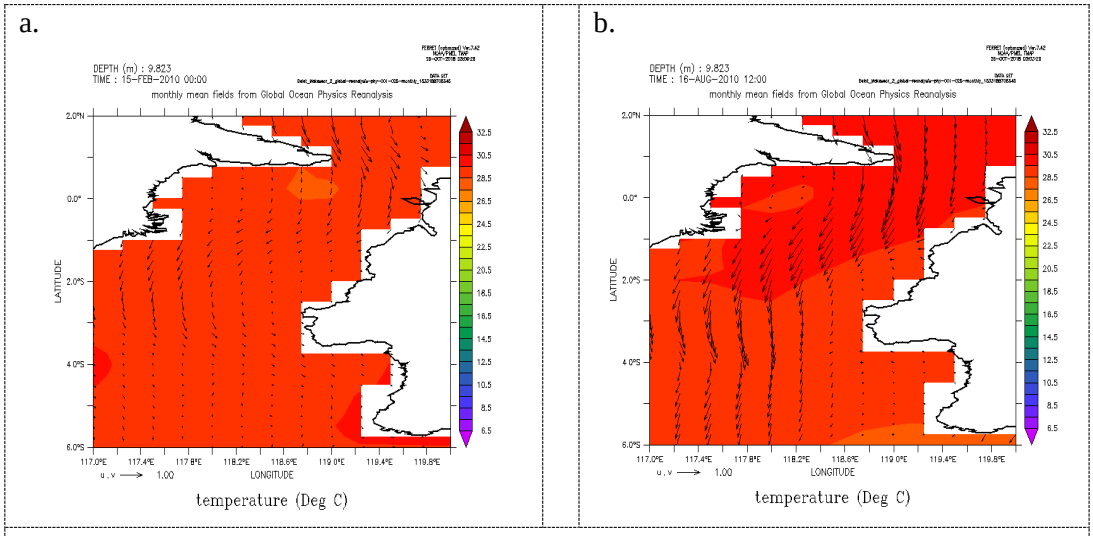


Figure 3. Temperature spatial distribution in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait during La Nina 2010 period.

Temperature distribution in February is relatively homogeneous throughout the waters area with a temperature of around 30°C. While in August in east monsoon, the temperature distribution is different 2°C where in the north of waters which start from latitude 2°S-2°N have a greater temperature is 30°C and at south until west part of waters which connection with Java Sea is from 0°-6°LS have a temperature around 28°C.

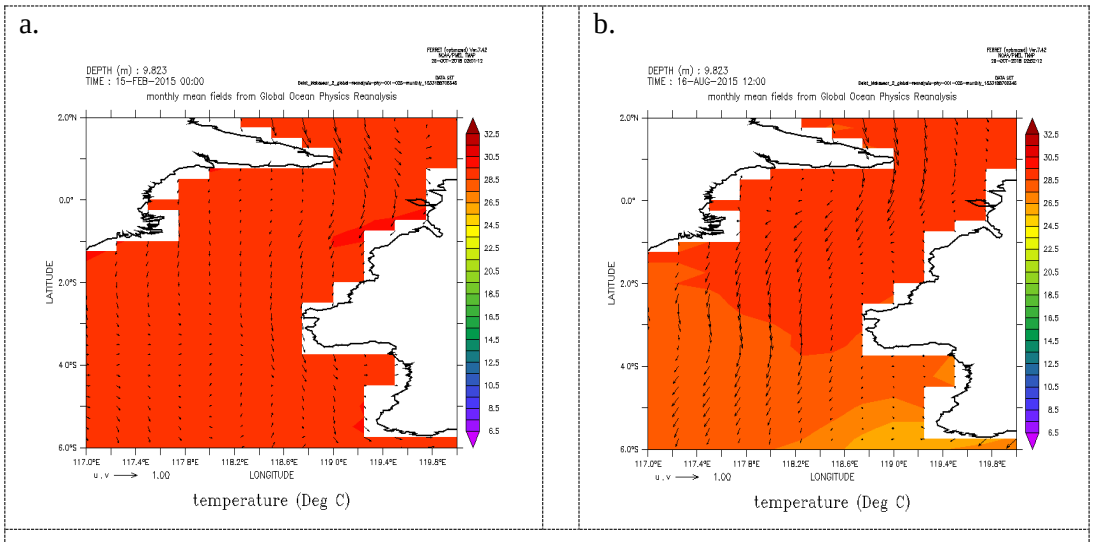


Figure 4. Temperature spatial distribution in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait during El Nino 2015 period.

In the El Nino 2015 period, the temperature distribution along the waters there is no significant change from the La Nina 2010 period is in February it has a temperature of 29°C as well as in August that decreased to 28°C in the south part of the strait, just only at the El Nino period, the temperature in the south-east is at longitude 118.5°-120°6-6.5°LS has a cooler temperature until 24°C due the influence of upwelling coming from east waters.

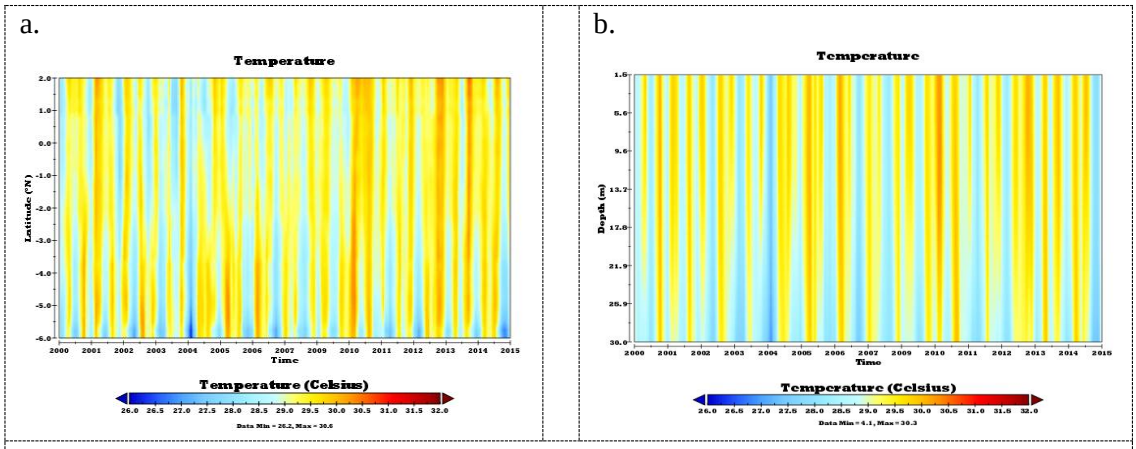


Figure 5. The average spatial (latitude) and temporal temperature distribution (a) and temperature vertical spatial distribution (b) at a depth of 9,8225 m (Mixed Layer) of Makassaar Strait.

The total average spatial distribution of temperatures along latitude 2°LU-6°LS from 2000 to 2015 on dominant shows two different temperature distributions in each year but there was a differences significant temperature anomaly in 2010 with 2015 where throughout 2010 in the figure has a dominant color dark orange which shows a high temperature of around 31°C than in 2015 with a dominant blue

color that shows a low temperature of 31°C. Based on the Ocean Nino Index (ONI) data in 2015 there was a strong El-Nino, causing sea level elevation in the western Pacific Ocean to fall compared to the Indian Ocean, so Arlindo will tend to weaken. According to Gordon (2005) that the variability of sea surface temperature in Indonesian waters, especially in the eastern part, is expected to follow Arlindo's fluctuations, when El-Nino sea surface temperature will drop while in the event of sea surface temperatures will rise.

Vertically, the surface temperature distribution is seen to a depth of 28 m. at a surface of 1.5 m to a depth of 28 m in 2010 has a thicker layer (mixed layer) which is still at a depth of 28 m, while in 2015 when the occurrence of El Nino showed no or thinning homogeneous layer that was not visible from the surface. The same thing with the statement (Kunarso, 2010) which says that when La Nina is strong, the upper boundary of the thermocline or the lower layer of the mixed layer decreases so that the homogeneous layer is mixed layer thicker. Whereas at the time of El Nino occurrence the lower limit of the mixed layer layer is thinning. This is due to the occurrence of La Nina when there was a buildup of water masses in the western Pacific and Indonesian waters so that it pressed down the upper limit of the thermocline than when the El Nino occurred.

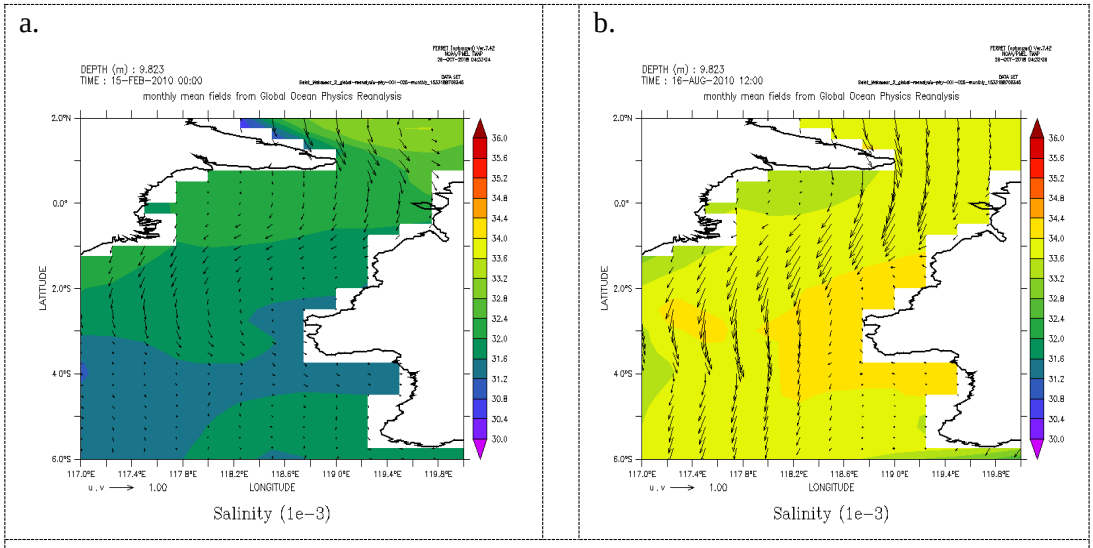


Figure 6. Salinity spatial distribution in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait waters in the La Nina 2010 period.

Salinity distribution in this La Nina period showed that the average salinity in the Makassar straits in February was lower than August, which ranged from 30.0 to 33.2 psu in February, and 32.5 to 34.4 psu in August. Salinity variations also occur between the north and south parts, especially in February where the southern part of the Makassar straits has a lower salinity than the northern part. Water mass that comes from pacific which go into Makassar strait in north part has high salinity is 33,2 psu that start decrease until 30,0 psu after the water mass bent through headland. In august, variation of salinity shown in west and north where the north part waters have salinity 34,4 psu and the west part waters is 32,5 psu. Salinity distribution in this month is visible following the flow pattern of water mass that through Makassar straits.

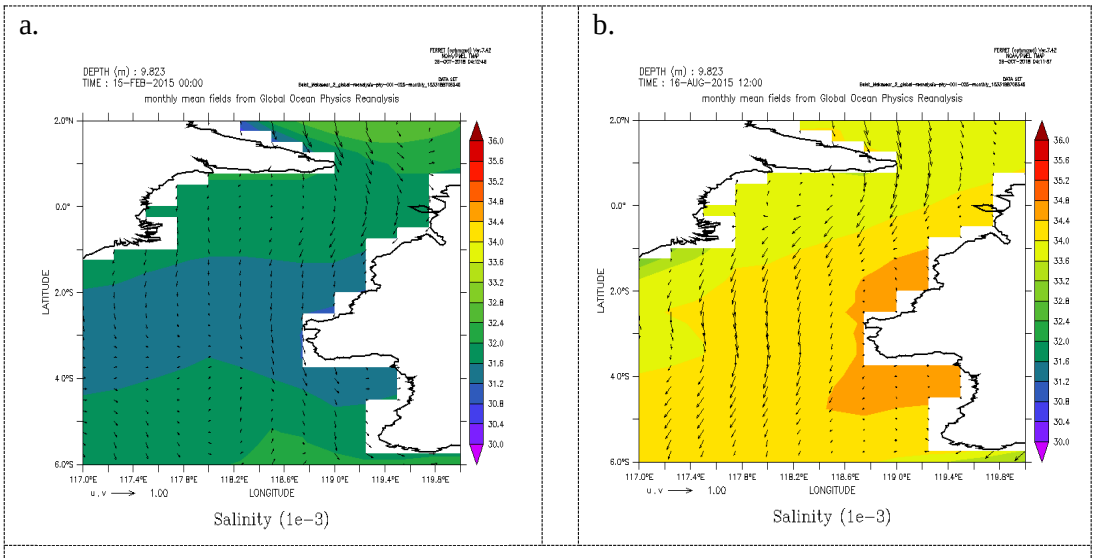


Figure 7. Salinity spatial distribution in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait waters in the El-Nino 2015 period.

The spatial distribution of Makassar straits salinity in the El-Nino 2015 event is generally the same as the distribution of salinity in the 2010 La-Nina event which is lower in February and higher in August. However, the incidence of El-Nino which was characterized by a long drought in Indonesia, so that the greater evaporation affected the salinity of the Makassar strait, which ranged from 30.2 to 32.7 psu in February and 32.9 to 34.6 psu in August. In the February, the waters with lower salinity shift to the center at 5 ° LS to 0 ° at 30.2 psu. The highest salinity is in the east to south, which is 34.6 psu and low salinity is in the northern part, starting from the entry of the water mass to the west with a value of about 30.2 psu.

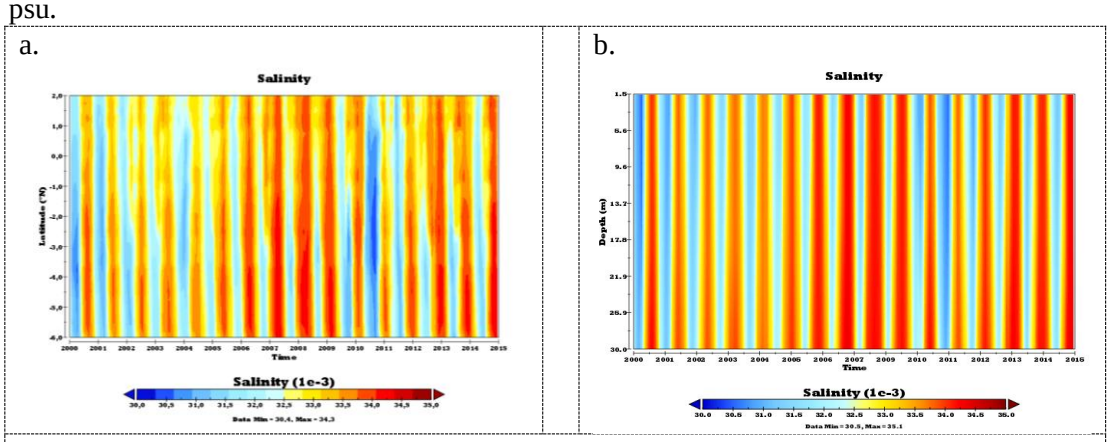


Figure 8. Average spatial total distribution of salinity (latitude) and temporal salinity (a) and salinity vertical spatial distribution, (b) at a depth of 9.8225 m (Mixed Layer) in the Makassar Straits.

The average spatial total distribution of salinity along latitude 2° N-6° S from 2000 to 2015 shows the almost same salinity every year but in 2010 up to early 2011 there was a significant decrease of salinity where in the image has dark blue has low salinity that reaches 30.0 psu. While in 2015 showed high salinity which is around 34.6 psu.

The vertical distribution of salinity that seen at a surface of 1.5 m to 28 m in 2010 is inversely proportional with temperature distribution so that the salinity of the mixed layer is thinner in 2010 when La Nina period than in 2015 when El Nino period.

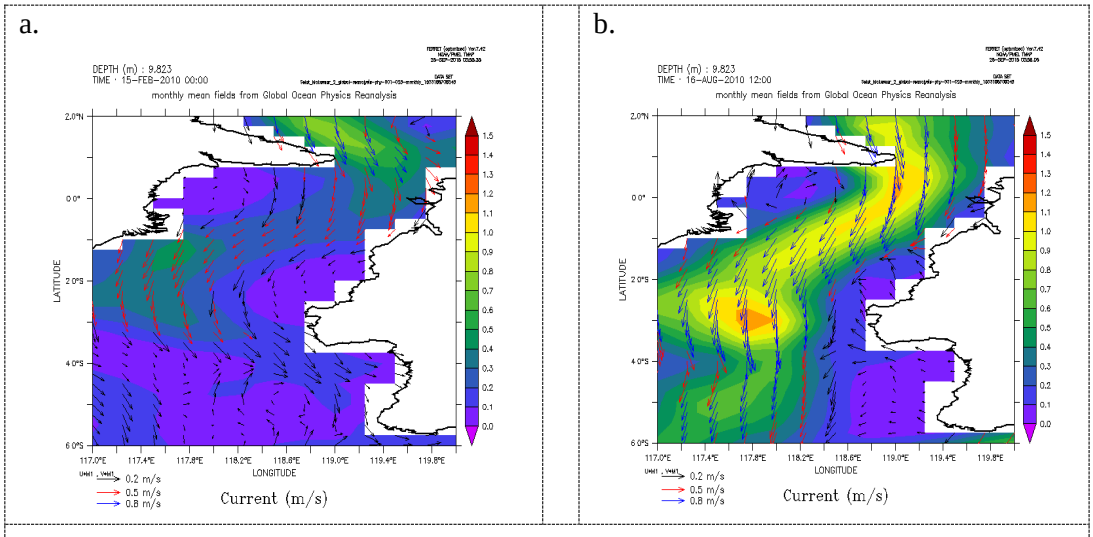


Figure 9. Ocean Current Speeds and Direction in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait of La Nina 2010 period

The circulation pattern of surface currents in the February shows the current pattern that through the Makassar Strait to the south and turns to east (Flores Sea). In the north part, the incoming water mass collides with the topography of the sea floor from the headland so that the current turns towards to the west by strengthening the current on the east side as it passes through the headland. While in August the current circulation of the south part of the Makassar straits turns to west (Java Sea) according to the direction of the monsoon wind. In 2010, there was an intensification of high currents until August in the middle of the strait with an average speed around 1 m/s than the current in February that representing the east monsoon which only around 0.1-0.3 m/s.

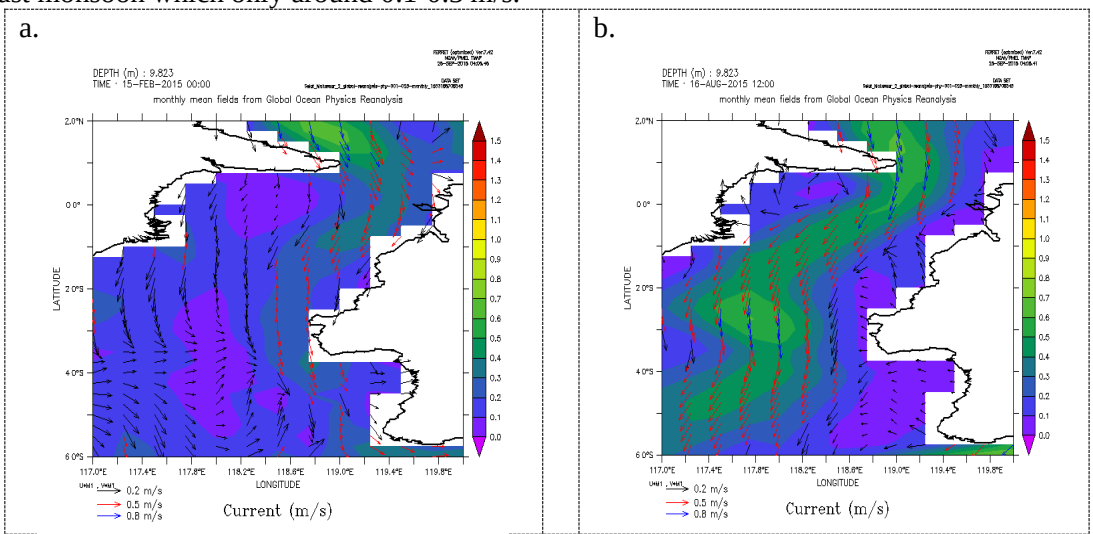


Figure 10. Ocean Current Speeds and Direction in February (a), August (b) at a depth of 9,823 m (Mixed Layer) of the Makassar Strait in El Nino 2015 period

The ocean currents in 9,823 m which there in mixed layer during El Nino 2015 period still show the same current pattern in the La Nina 2010 period. However, in El Nino period, the current speeds in February reached 0.2 m/s and in August the current speeds increased to 0.6 m/s where the current speeds in this year is weaker than in 2010 when La Nina period.

4. Conclusion

The current pattern in mixed layer in the La Nina 2010 period is stronger than the El Nino 2015 period with the highest intensification occurring in East Monsoon (August). The mixed layer temperature distribution during the La Nina 2010 period was higher than the El Nino 2015 period and was more homogeneous in the west monsoon than the east monsoon. The mixed layer salinity distribution when the La Nina 2010 period was lower than the El Nino 2015 period and more varied than the temperature distribution. El Nino and La Nina were more clearly influential on east monsoon (August).

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