Interannual variability of sea surface height difference between western Pacific Ocean and eastern Indian Ocean and its effect to geostrophic current in Lombok Strait

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Abstract. Interannual variability of sea surface height (SSH) in western Pacific Ocean and eastern Indian Ocean occurs as a result of the ENSO phenomena. This variability affects SSH difference between both of those oceans. In normal condition, SSH in western Pacific Ocean is higher than in eastern Indian Ocean which causes a current that passes through Indonesia which known as the Indonesian Throughflow (ITF). This study used SSH and geostrophic currents data from 1993 to 2015 which obtained from AVISO satellite altimetry data to determine the variability of SSH difference in ENSO condition which represented by the sea surface temperature (SST) anomaly of Niño 3.4 data from NOAA and its relation to the geostrophic currents in Lombok Strait which is one of the ITF crossing path. The result of the correlation calculation of ENSO condition to SSH difference between western Pacific Ocean and eastern Indian Ocean shows the negative value. It means that SSH difference at both oceans have opposite condition that when El Niño happened SSH in western Pacific Ocean is lower than the eastern Indian Ocean and when La Niña happened SSH in the western Pacific Ocean is higher than the eastern Indian Ocean. The SSH difference does not affect the direction of geostrophic currents but affects its speed.

1. Introduction

ENSO (El Niño Southern Oscillation) is a phenomenon of climate variability that affects Indonesia, equatorial Pacific and other parts of the world [1]. The ENSO phenomenon consists of two events, El Niño and La Niña. This phenomenon can give negative impacts to the community directly such as prolonged droughts and forest fires, and excessive rainfall which causes the flash flood. El Niño occurs when sea surface temperature (SST) in the eastern and central Pacific Ocean increase which associated to the reduction of rainfall in Indonesia whereas when La Niña occurs it shows the opposite condition [2, 3]. The phenomenon of El Niño and La Niña can be studied from several indicators such as sea surface temperature anomaly, southern oscillation index, sea level altitude, and Indonesian Throughflow or commonly called as ITF [1].

ITF is a system of marine circulation in Indonesian waters where a flow path takes the mass of water from the Pacific Ocean to the Indian Ocean [4]. The current occurs due to differences in sea surface height between the Pacific Ocean and Indian Ocean [5]. The occurrence of ITF is mainly caused by the
tropical surface of the Western Pacific Ocean is higher than in the eastern Indian Ocean, it produces a pressure gradient which drives a flow of currents from the Pacific Ocean to the Indian Ocean as its result [6]. The important indicators to be observed for assessing the ITF are the sea surface height (SSH) in the Pacific and Indian Oceans and the variability of sea surface temperature (SST) in Indonesian waters [1].

SSH differences variability in the Pacific Ocean and Indian Ocean has been calculated by subtracting the SSH of Pacific Ocean with the SSH of Indian Ocean [7]. The result shows that the calculations during the El Niño years, the value of SSH difference is negative while at the time La Niña is positive. The results of the calculations in that study can be seen in table 1 and 2.

Table 1. Monthly sea surface height difference values to ENSO in January, February, March, April, May, and June 1993 - 2015[7]

| Time  | Jan  | Feb  | Mar  | Apr  | May  | Jun  |
|-------|------|------|------|------|------|------|
| 1993  | -0.06| 0.00 | -0.02| -0.10| -0.08| -0.06|
| 1994  | -0.09| -0.05| 0.00 | -0.03| -0.05| -0.02|
| 1995  | -0.08| -0.08| -0.03| -0.03| -0.03| -0.01|
| 1996  | -0.03| -0.02| -0.02| 0.02 | -0.03| -0.04|
| 1997  | -0.10| -0.06| -0.09| -0.07| -0.10| -0.08|
| 1998  | -0.09| -0.07| -0.04| 0.00 | 0.01 | 0.03 |
| 1999  | 0.01 | 0.05 | 0.07 | 0.04 | 0.00 | 0.00 |
| 2000  | 0.00 | 0.03 | 0.04 | 0.00 | -0.03| -0.01|
| 2001  | -0.01| 0.03 | 0.02 | 0.00 | -0.02| -0.01|
| 2002  | -0.09| -0.03| -0.07| -0.06| -0.06| -0.04|
| 2003  | -0.12| -0.11| -0.03| -0.01| -0.01| -0.05|
| 2004  | -0.04| 0.00 | -0.02| -0.06| -0.08| -0.06|
| 2005  | -0.05| -0.05| -0.02| -0.03| -0.02| -0.01|
| 2006  | -0.02| 0.01 | 0.05 | 0.03 | 0.01 | 0.02 |
| 2007  | -0.04| -0.05| -0.02| -0.04| -0.05| -0.01|
| 2008  | 0.07 | 0.10 | 0.08 | 0.02 | -0.03| 0.00 |
| 2009  | 0.02 | 0.03 | 0.02 | 0.01 | -0.03| -0.01|
| 2010  | -0.12| -0.11| -0.06| -0.01| 0.01 | 0.04 |
| 2011  | 0.01 | 0.01 | 0.01 | -0.04| -0.04| -0.04|
| 2012  | 0.02 | 0.00 | 0.03 | -0.03| -0.02| 0.02 |
| 2013  | 0.01 | -0.01| 0.02 | 0.05 | 0.02 | 0.00 |
| 2014  | -0.02| -0.03| -0.08| -0.09| -0.10| -0.07|
| 2015  | -0.08| -0.13| -0.12| -0.11| -0.13| -0.14|

| Mean  | -0.04| -0.02| -0.01| -0.02| -0.04| -0.02|

Table 2. Monthly sea surface height difference values to ENSO in July, August, September, October, November, and December 1993 - 2015[7]

| Time  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|-------|------|------|------|------|------|------|
| 1993  | -0.06| -0.03| -0.02| 0.01 | -0.01| -0.07|
| 1994  | -0.01| 0.04 | 0.01 | 0.05 | 0.03 | -0.05|
| 1995  | 0.03 | 0.06 | 0.06 | 0.05 | 0.05 | 0.01 |
| 1996  | -0.01| 0.01 | 0.04 | 0.03 | 0.03 | -0.03|
| 1997  | -0.07| -0.04| -0.05| -0.06| -0.07| -0.10|
| 1998  | 0.01 | 0.04 | 0.06 | 0.08 | 0.04 | -0.01|
|
|---|---|---|---|---|---|---|
| Time | Jul | Aug | Sep | Oct | Nov | Dec |
| 1999 | 0.04 | 0.05 | 0.07 | 0.10 | 0.04 | 0.00 |
| 2000 | 0.02 | 0.03 | 0.05 | 0.03 | 0.01 | -0.03 |
| 2001 | -0.02 | 0.01 | 0.04 | 0.05 | 0.01 | -0.05 |
| 2002 | -0.03 | -0.04 | -0.05 | -0.07 | -0.10 | -0.14 |
| 2003 | -0.02 | 0.00 | 0.02 | 0.06 | -0.01 | -0.04 |
| 2004 | -0.05 | -0.01 | 0.04 | 0.03 | 0.02 | -0.03 |
| 2005 | 0.01 | 0.01 | 0.04 | 0.03 | 0.01 | -0.03 |
| 2006 | 0.01 | 0.01 | 0.02 | 0.03 | -0.01 | -0.04 |
| 2007 | 0.03 | 0.05 | 0.08 | 0.11 | 0.09 | 0.06 |
| 2008 | 0.05 | 0.09 | 0.08 | 0.05 | 0.03 | 0.05 |
| 2009 | -0.01 | 0.01 | 0.03 | -0.01 | -0.05 | -0.11 |
| 2010 | 0.04 | 0.04 | 0.06 | 0.02 | 0.03 | 0.00 |
| 2011 | -0.02 | 0.02 | 0.09 | 0.10 | 0.07 | 0.03 |
| 2012 | 0.04 | 0.08 | 0.07 | 0.06 | 0.00 | 0.00 |
| 2013 | 0.00 | 0.02 | 0.05 | 0.04 | -0.01 | 0.01 |
| 2014 | -0.04 | -0.02 | 0.00 | 0.01 | -0.01 | -0.05 |
| 2015 | -0.11 | -0.11 | -0.07 | -0.07 | -0.09 | -0.13 |
| Mean | -0.01 | 0.01 | 0.03 | 0.03 | 0.00 | -0.03 |

Since the value of SSH difference yields a small value, so to compare the pattern between SSH difference with Nino 3.4 SST anomaly then SSH difference values were multiplied by 10 to see the opposite pattern in those comparison graph (figure 1). It shows that the Niño 3.4 SST anomaly depicted by a yellow line has an opposite graph pattern of the SSH difference of the western Pacific Ocean and the eastern Indian Ocean depicted by a blue line.

![Figure 1](image.png)

**Figure 1.** Comparative of Niño 3.4 SST Anomaly (yellow line) to SSH difference (grey line) between western Pacific Ocean and eastern Indian Ocean [7]. SSH difference is multiplied by 10 to better see the pattern.

This study extends the results of earlier work [7] and provides the correlation between interannual sea surface height in the western Pacific Ocean and eastern Indian Ocean to ENSO indices. ITF is a geostrophic transport at a maximum depth of 100 meters (upper layer) observed based on the difference
from the pressure gauge with absolute flow determined by the existing tidal and its speed section is corrected by the Acoustic Doppler Current Profiler [8]. Therefrom, we used the geostrophic velocity around Lombok strait to indicate the changing of SSH of both oceans due to ENSO events.

2. Data and method
The daily sea surface height (SSH) data from January 1993 to December 2015 with 0.25° x 0.25° resolution were provided by AVISO data center of CNES (Centre National d’Etudes Spatiales) based on TOPEX/Poseidon, Jason-1, and ERS-2 data is used in this study. The data have been corrected for all geophysical corrections includes ionospheric, dry and wet tropospheric delays, sea state bias, solid Earth, ocean and pole tides, ocean tide loading and inverted barometer correction. The data have also been corrected for instrumental drifts [9]. Those daily data were converted to monthly data by using monthly average calculation. The study areas were Western Pacific Ocean (125°-145° E; 10°-0° N) and Eastern Indian Ocean (110°-130° E; 10°-20° S) (figure 2) where those locations are based on the theory of the ITF attributed to differences in sea surface height between the Pacific Ocean and the Indian Ocean [5].

SSH in Western Pacific were compared to SSH in eastern Indian Ocean by computing the difference of SSH in both oceans. The assumptions used are based on the difference in sea level between the Pacific and Indian Oceans [5] where the Western Pacific Ocean is higher than that of the eastern Indian Ocean [6 in 4]. Therefrom the value of SSH in the western Pacific Ocean were subtracted by SSH in the eastern Indian Ocean [7]. A simple formulation to calculate the difference between SSH is as follows:

\[ \Delta \text{SSH} = \text{SSH}_{\text{po}} - \text{SSH}_{\text{io}} \]

Where \( \Delta \text{SSH} \) is the differences of sea surface height, \( \text{SSH}_{\text{po}} \) is the sea surface height of the western Pacific Ocean, and \( \text{SSH}_{\text{io}} \) is the sea surface height of the eastern Indian Ocean.

![Figure 2. Research location. The red rectangles are the location of SSH data. The yellow box is the location of geostrophic current data which is Lombok Strait.](image_url)
There are several indices used to monitor the tropical Pacific, all of which are based on sea surface temperature (SST) anomalies averaged across a given region. Usually the anomalies are computed relative to a base period of 30 years [10]. The Niño 3.4 index and the Oceanic Niño Index (ONI) are the most commonly used indices to define El Niño and La Niña events where the region of Niño 3.4 is located in 5N-5S, 170W-120W. Niño 3.4 index is the SST anomalies of Nino 3.4 region which may be thought of as representing the average equatorial SST across the Pacific from about the dateline to the South American coast. The Niño 3.4 index typically uses a 5-month running mean, and El Niño or La Niña events are defined as when the Niño 3.4 SST exceeds +/- 0.4°C for a period of six months or more. Whereas, ONI uses the same region as the Niño 3.4 index. It uses a 3-month running mean, and to be classified as a full-fledged El Niño or La Niña, the anomalies must exceed +0.5°C or -0.5°C for at least five months [10]. In this study, we used the monthly SST anomaly of Niño 3.4 from NOAA to determine the El Niño and La Niña episode, where the anomaly was taken toward the monthly average of SST Niño 3.4 during the period 1993 – 2015. When the monthly anomaly of SST Niño 3.4 is greater than 0.5 then is expressed as El Niño period and when monthly anomaly of SST Niño 3.4 value is lower than -0.5 then is expressed as La Niña period, respectively.

This study conducted a correlation analysis to find out how the relationship is between the parameters of sea surface height in the western Pacific Ocean and eastern Indian Ocean to the SST anomaly in Niño 3.4 region. In addition, correlation analysis was also performed on the SSH difference between the western Pacific Ocean and the eastern Indian Ocean to the occurrence of ENSO.

The variables which used in the correlation analysis are the anomaly of SST Niño 3.4 as the independent variable (x) which is considered to represent the incidence of El Niño and La Niña and the monthly average data of SSH, SSH difference in the western Pacific Ocean and the eastern Indian Ocean at the same event as the dependent variable (y). The used correlation equation is Pearson correlation (1749) which is formulated as follows [11]:

$$r_{xy} = \frac{n \Sigma xy - \Sigma x \Sigma y}{\sqrt{[n \Sigma x^2 - (\Sigma x)^2][n \Sigma y^2 - (\Sigma y)^2]}}$$

Where \( r \) is Pearson correlation, \( n \) is amount of sample, \( x \) is independent variable, and \( y \) is dependent variable. The level of relationship between the variables in the correlation analysis is based on the values in table 3 [12].

| Interval of correlation | Level of relationship |
|------------------------|-----------------------|
| 0 – 0.199              | Very low              |
| 0.20 – 0.399           | Low                   |
| 0.40 – 0.599           | Moderate              |
| 0.60 – 0.799           | Strong                |
| 0.80 – 1.00            | Very strong           |

The Geostrophic current is caused by geostrophic balance occurring due to horizontal pressure gradient which is working on moving water masses, and balanced by the coriolis force [13]. The data of absolute geostrophic currents for 23 years from 1993 until 2015 with resolution 0.25° x 0.25° were also provided by AVISO. The difference of the sea water mass physical condition between one place and another produces a pressure gradient force which triggers the mass flow of seawater. The horizontal pressure force moves the current in a horizontal direction and in its movement will be influenced by the coriolis force which arising from the rotation of the earth. The geostrophic current at the sea surface consists of two main components such as \( u \) and \( v \). The speed and direction of the geostrophic current is determined by calculating the resultant of the components \( u \) and \( v \) using the formula:

$$R = \sqrt{u^2 + v^2}$$

(3)
Where $R$ is the resultant of $u$ vector and $v$ vector (m/s), $u$ is the speed of geostrophic current in the x direction (m/s), and $v$ is the speed of geostrophic current in the y direction (m/s).

The measurement of the geostrophic current on the surface ($z = 0$) of the altimetry satellite is related to the slope of water surface, that is absolute dynamic or absolute dynamic topography. Dynamic topography is the difference in sea level above the geoid [14]. In AVISO, the mean dynamic topography (MDT) is obtained by averaging dynamic topography [15]. The calculation of absolute dynamic topography is as follows:

$$ADT = MDT + SLA$$

Where $ADT$ is the absolute dynamic topography (m), $MDT$ is the mean dynamic topography (m), and $SLA$ is sea level anomaly (m).

The geostrophic current of Lombok Strait ($7° - 9°$ S and $115° - 116°$ E) shown by red rectangle in figure 2 is chosen because that location is one of the exit pathway of ITF sea water mass to Indian Ocean [1]. The absolute geostrophic current velocity obtained from the calculation using absolute dynamic topography data [16] as the formula below:

$$V_s = \frac{1}{f g} \frac{\delta \zeta}{\delta x} \quad U_s = -\frac{1}{f g} \frac{\delta \zeta}{\delta y}$$

Where $U_s$ is zonal surface geostrophic current velocity x (m/s), $V_s$ is meridional surface geostrophic current velocity (m/s), $\zeta$ is absolute dynamic topography (m), $g$ is gravity (m/s²), and $f$ is the coriolis parameters.

The selection of geostrophic currents as a medium to verify the SSH since geostrophic currents is the current occurring at sea surface due to the influence of horizontal pressure gradient forces and is balanced by the coriolis force [13, 17]. The sea level difference causes the horizontal gradient so that the geostrophic current can be used as a tool to verify the changing of SSH in western Pacific Ocean and eastern Indian Ocean when ENSO occurred.

3. Result and discussion

3.1. Correlation between sea surface height (SSH) and ENSO

The calculation results show that the correlation value between Niño 3.4 SST anomalies and SSH in the western Pacific Ocean with R value of -0.79 (figure 3). This suggests a strong relationship between the parameters of SSH in the western Pacific Ocean and Niño 3.4 SST anomalies.

![Figure 3](image-url)
The relationship between these two parameters indicates that the ENSO phenomenon affects SSH in the western Pacific Ocean region. The negative value on the correlation coefficient calculation results show the opposite relationship between the two parameters. The opposite relationship explains that when the SST anomalies in Niño 3.4 region increased (decreased), the SSH in the western Pacific Ocean decreased (increased) respectively.

The calculation of the correlation between SST Niño 3.4 anomalies with SSH in the eastern Indian Ocean showed a result of -0.62 (figure 4). This value indicates a close relationship between the two parameters studied.

![Figure 4. Scatter Plot of Niño 3.4 Sea Surface Temperature Anomaly and Sea Surface Height in Eastern Indian Ocean.](image)

Negative values indicate an existing relationship has opposite meaning that when the Niño 3.4 SST anomaly is positive or when the El Niño occurs then the SSH in the eastern Indian Ocean becomes lower. When La Niña happened, the Niño 3.4 SST anomaly is negative then the SSH in the eastern Indian Ocean becomes higher.

### 3.2. Sea surface height condition in ENSO condition

The results of SSH data processing in the western Pacific Ocean and the eastern Indian Ocean indicate a variation in value throughout the year. The variation is influenced by the ENSO phenomena. Sea level can be used as a signal for the occurrence of ENSO and has a different response depending on the period of the ENSO itself [18]. This is similar to the results of this study. The influence of ENSO on SSH variations is clearly visible in both the western Pacific Ocean and the eastern Indian Ocean.

The higher Pacific Ocean SSH trend compared to the Indian Ocean is also affected by the ENSO phenomenon. Stated in the previous research [6], that the western Pacific Ocean is higher than the eastern Indian Ocean. The results of data processing conducted in this study is somewhat different with the previous references. The height of the SSH in the western Pacific Ocean can also be lower than the SSH elevation in the eastern Indian Ocean (figure 5).
Figure 5. Comparative between SSH (green line: eastern Indian Ocean; orange line: western Pacific Ocean) and ENSO which showed by the blue bars as the value of Niño 3.4 SST anomaly (red rectangle: El Niño condition when the value of Niño 3.4 SST anomaly is greater than 0.5; green rectangle: La Niña condition when the value of Niño 3.4 SST anomaly is lower than -0.5; yellow rectangle: neutral condition when the value of Niño 3.4 SST anomaly is between 0.5 and -0.5) in 1993-2015.

Figure 5 shows that when the SST anomaly is greater than 0.5, the western Pacific Ocean SSH shown by the yellow line graph is lower than that of the East Indian Ocean SSH indicated by a green line graph. Anomalous values greater than 0.5 indicate the occurrence of El Niño phenomena. This is in accordance with the results of data processing which shows that the value of the SSH difference between the two oceans is negative when the El Niño occurs (table 1 and 2). An example of a comparison chart between SSHs in both oceans when the El Niño is marked with a red rectangle in figure 5.

In neutral condition, when the value of Niño 3.4 SST anomaly is between 0.5 and -0.5 the range of SSH in the western Pacific Ocean is mostly higher than the SSH in the eastern Indian Ocean except in the beginning of 2014 because it tends to be an El Niño condition. An example of a comparison chart between the SSH in both oceans when the neutral condition is indicated by a yellow rectangle in figure 5. This is in accordance with the previous reference which states that SSH in the western Pacific Ocean is higher than the eastern Indian Ocean normally [6].

As the normal condition of the western Pacific Ocean is higher than that of the eastern Indian Ocean, when the anomalous value of SST Niño 3.4 is smaller than -0.5 similar conditions occur. When La Niña onset applies, the western Pacific Ocean is higher than the Eastern Indian Ocean. This has an accordance with the results of data processing showing that the value of the SSH difference between those two oceans is positive (table 1). The comparison graph between the SSHs in both oceans when La Niña is marked with a green box in figure 5.

3.3. Correlation between SSH difference and ENSO

Correlation calculations were also performed on the difference between SSH in the western Pacific Ocean and the eastern Indian Ocean with an anomaly of SST Niño 3.4 to find out how strong the relationship between the SSH difference in both oceans to ENSO. The result shows that the correlation value is -0.63 (figure 6). It shows a strong opposite relationship.
When we compared between the mean values of the SSH difference during the years 1993 to 2015 against the average sea surface height difference at the time of El Niño and La Niña clearly shows that at the time of El Niño in the western Pacific Ocean will be lower than the eastern Indian Ocean And the opposite condition occurs at the time of La Niña (figure 6). Based on the graph in figure 7, it is shown that when El Niño occurs in April, the average value of the SSH difference between the western Pacific Ocean and the eastern Indian Ocean has a great negative value.

![Figure 6. Scatter Plot of Niño 3.4 Sea Surface Temperature Anomaly and Sea Surface Height Difference of the Western Pacific Ocean - Eastern Indian Ocean.](image)

![Figure 7. Comparative between the average of sea surface height difference in the Western Pacific Ocean and Eastern Indian Ocean. The green line is the average value along 1993 to 2015. The blue line is the average value when La Niña event along 1993 to 2015. The red line is the average value when El Niño event along 1993 to 2015.](image)
The obtained result shows that the sea level in the western Pacific Ocean and the eastern Indian Ocean varies with the incidence of ENSO. Figure 7 shows that if El Niño occurs in April the decrease of SSH in the western Pacific Ocean can reach more than -0.2 m.

3.4. Verification of sea surface height difference value using geostrophic current velocity during ENSO

As our previous results [7], ENSO events apply increase/decrease in SSH difference. Taking the example of El Niño events in June and November 1997 and La Niña events in June and November 1999 (figure 8 and 9), shown the pattern of geostrophic currents direction in the Lombok Strait area (7° - 9° S and 115° - 116° E). The current moves from the higher SSH to the lower SSH however, based on the current pattern on both figures show no significant change in current direction at the time when El Niño occurred even though based on calculation in this research is SSH in western Pacific Ocean becomes lower than SSH in eastern Indian Ocean.

Figure 8. Geostrophic current pattern in surrounding Lombok Strait when El Niño in June 1997 (above) and La Niña in June 1999 (below).
Based on the example of ENSO events in June 1997 and 1999 in figure 8, there was no significant change in the direction of the geostrophic current. However, based on the color gradient display, the geostrophic current velocity in June 1997 tended to be lower than that in June 1999.

**Figure 9.** Geostrophic current pattern in surrounding Lombok Strait when El Niño in November 1997 (above) and La Niña in November 1999 (below).

Based on the example of ENSO events in November 1997 and 1999 in figure 9, there is change in the direction of currents that occur around the Lombok strait. It changes direction. The color gradient display shows the geostrophic current velocity in November 1997 is also tended to be lower than in November 1999.

Reviewing from the parameters of the geostrophic currents velocity, there is an influence on the phenomenon of the ENSO. Verification of SSH differences to the current velocity in Lombok Strait
during ENSO can be seen in figure 10. The period of ENSO occurrence selected was from 1997 to 2001. The Elements of El Niño and La Niña were strong or weak.

![Figure 10](image-url)

**Figure 10.** Geostrophic current velocity in Lombok Strait during ENSO in 1997 – 2001.

The average geostrophic current velocity in the Lombok Strait (7° - 9° S and 115° - 116° E) at the time of La Niña tends to be higher than at the time of the El Niño. The difference that occurred in the example of ENSO events in 1997 and 1998 was 0.05 m/s between the current velocity of El Niño and La Niña. The weaker current velocity conditions at the time of El Niño is due to lower SSH of western Pacific Ocean than the SSH in the eastern Indian Ocean.

Based on the graph of the average of geostrophic current velocity in figure 10 shows that there is a tendency of seasonal patterns in geostrophic currents around the Lombok strait. In the late and early months of the years the trend of geostrophic current velocity in the Lombok Strait was higher than in the mid-year period. While in November 1997, there was an increase in the velocity of geostrophic currents as in general, but the increase was smaller than when El Niño was absent. When La Niña occurs the SSH conditions of the western Pacific Ocean are higher than those in the eastern Indian Ocean. This is in accordance with normal conditions, but in the case of La Niña SSH in the western Pacific Ocean tends to be higher than normal conditions. This has an impact to the increasing of geostrophic current velocity in the Lombok Strait region.

The change of direction of geostrophic currents in the Lombok Strait in El Niño phase is as the nature of the geostrophic term itself, it will flow from the higher pressure to the lower one related to depth. The El Niño and La Niña modifies the mean sea level, hence the depth of the western Pacific, in term of sifting it to the east and west of the Pacific Ocean, respectively. Within El Niño phase the sea level in Indian Ocean is higher than in the Makassar Strait, therefrom we get reverse direction of the geostrophic flow.

4. **Conclusion**

ENSO (El Niño Southern Oscillation) affects the sea level in the western Pacific Ocean and the eastern Indian Ocean. When the El Niño occurs SSH in the western Pacific Ocean is lower than that in the eastern Indian Ocean whereas at the time of La Niña SSH in the western Pacific Ocean is higher than the western Pacific Ocean. The variability of SSH affects the geostrophic current velocity in Lombok Strait as the one of the exit pathway location of ITF water mass. The sea level difference in both oceans
affects the geostrophic currents in the Lombok Strait. When sea level of the western Pacific Ocean is lower than the eastern Indian Ocean, the currents velocity in the Lombok Strait becomes lower than the normal condition. Meanwhile, when the sea level of the western Pacific Ocean is higher than the eastern Indian Ocean, the speed of geostrophic currents in the Lombok Strait becomes faster than the normal condition.

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