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Effect of ENSO and IOD on the Variability of Sea Surface Temperature (SST) in Java Sea

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Abstract. El-Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) climate variability are global climate variability that can affect oceanographic conditions including SST (Sea Surface Temperature). Located between two oceans, the Indian and the Pacific, the variability of SST in Indonesia is influenced by ENSO and IOD. Previous studies have shown that the influence of ENSO in the Java Sea depends on the season, and while positive (negative) IOD decreases (increase) SST in Indonesian seas. This study aims to examine the effect of ENSO and IOD climate variability on the variability of SST in the Java Sea. SST data are obtained from NOAA Pathfinder and Aqua MODIS satellite image data, while wind data is obtained from ECMWF satellite imagery with long observed data for 36 years (1982-2017) using quantitative methods in spatial and temporal, we found that the influence of ENSO and IOD in Java Sea based on the intensity of the anomaly. The intensity of ENSO which is stronger can affect SST more than IOD.

1. Introduction

Indonesia is a maritime country in the equatorial region that has strategic geographical location lies on two continents i.e Asia and Australia and two oceans i.e Indian and Pacific. Therefore, Indonesia is influenced by global of atmospheric circulation and global of ocean circulation. Global climate variability that affects atmospheric and oceanographic conditions in Indonesia is ENSO (El-Niño Southern Oscillation) and IOD (Indian Ocean Dipole) [1].

Changes of SST on the waters are strongly influenced by climate variabilities such as ENSO and IOD. ENSO is a phenomenon formed due to the presence of SST (Sea Surface Temperature) anomalies in the Pacific Ocean Equator region. ENSO is divided into El-Niño and La-Niña [2-4]. While, IOD is a phenomenon that occurs in the Indian Ocean due to differences in SST anomalies between the western and eastern Indian Ocean region [5-6].

Java Sea is one of the waters in Indonesia that is affected by global climate phenomena such as ENSO and IOD due to its geographical location adjacent to the Indian Ocean and Pacific Ocean, in addition to that the Java Sea has become a monsoon passageway that changes seasonal its direction. Northwest monsoon, winds flow from the South China Sea to the Java Sea through Natuna and the Karimata Strait, while in southeast monsoon, winds flow from Australia to Java Sea [4].

Research on climate variability such as ENSO related to SST variability in the Java Sea has been carried out by Wirasatriya [5] that in August during El Niño conditions, SST was lower than during La Niña conditions. Whereas in January during El Niño conditions, SST was higher than La Niña conditions, it shows that in the Java Sea, the ENSO climate variability depends on the season. But this research only examine the influence of ENSO which neglects the influence of IOD. As stated by reference [1] Indonesian Seas are also affected by IOD climate variability. In the present study, we found that the effect of ENSO on the variability of SST in the Java Sea depends on the season, while the effect of IOD does not depend on the season.



2. Data and Methods

We used long observed data for 36 years period i.e 1982-2017. For SST data, we used high spatial and temporal resolution data of the Advanced Very High Resolution Radiometers (AVHRR) Pathfinder version 5.2 Level-3, i.e daily with spatial resolution $0.04^\circ \times 0.04^\circ$ for observation periode 1982-2002 provided by ftp.nodc.noaa.gov, and used Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua Level-3, i.e., daily with spatial resolution $0.04^\circ \times 0.04^\circ$ for observation periode 2003-2017 provided by oceancolor.gsfc.nasa.gov. The algorithm for generating SST Pathfinder (PFFST) developed by C. Walton [6] while MODIS SST is described by Brown and Minnet [7].

To investigate the formation mechanism of SST pattern in Java Sea, we used surface wind data obtained from 6 hourly ERA interim data with grid interval of $0.125^\circ \times 0.125^\circ$ [8], i.e monthly for observation periode 1982-2017 which can be downloaded from www.ecmwf.int.

ENSO climate variability index data used ONI (Oceanic Niño Index) from the National Oceanic and Atmospheric Administration (NOAA) provided by www.cpc.noaa.gov. ONI index is the anomalies of SST in the Niño 3.4 region (5°N - 5°S , 120° - 170°W) [9], based on the period of 1982-2017. The threshold for determining El Niño and La Niña period is $\pm 0.5^\circ\text{C}$ [10]. While IOD climate variability index data used DMI (Dipole Mode Index) provided by www.jamstec.go.jp. DMI is a value derived from differences in sea surface temperature anomalies in the West Indian Ocean (10°N - 10°S and 50°E - 70°E) and East Indian Ocean (10°S - 0°U and 90°E - 110°E) [11], based on the period of 1982-2017. The threshold for determining the period of positive IOD and negative IOD is $\pm 0.25^\circ$.

We composed all the parameters into monthly means, and then used to derived monthly climatologies by using the following equation [12] :

$$\bar{X}(x, y) = \frac{1}{n} \sum_{i=1}^n xi(x, y, t) \quad (1)$$

where $\bar{X}(x, y)$ is monthly mean value or monthly climatology value at position (x, y) , $xi(x, y, t)$ is i th value of the data at (x, y) position and time t . Furthermore, n is number of data in 1 month and number of monthly data in 1 period of climatology (i.e., from 1982 to 2017 = 36 data) for monthly calculation and monthly climatology calculation, respectively. If xi is a hollow pixel, that pixel is excluded in the calculation.

3. Result and Discussion

3.1 Seasonal variations of SST in Java Sea

Seasonal distribution of SST in Java Sea is presented in figure 1, we show the January, April, August, and November periods to represent the northwest (NW) monsoon, transition I, southeast (SE) monsoon. We also presented seasonal variations of wind to show the mechanism of seasonal wind in influencing changes seasonal SST [5].

The distribution of SST in the Java Sea in the NW monsoon and SE monsoon shows that the variability of SST is lower than during the transition I monsoon and transition II monsoon, but in NW season, the variability of SST is relatively warm, whereas, in the SE season, relatively cold. During the transition I and transition II monsoon, SST is dominantly warm, this is in accordance with the previous study [4] that the highest SST in Indonesia occurs during the transition monsoon.

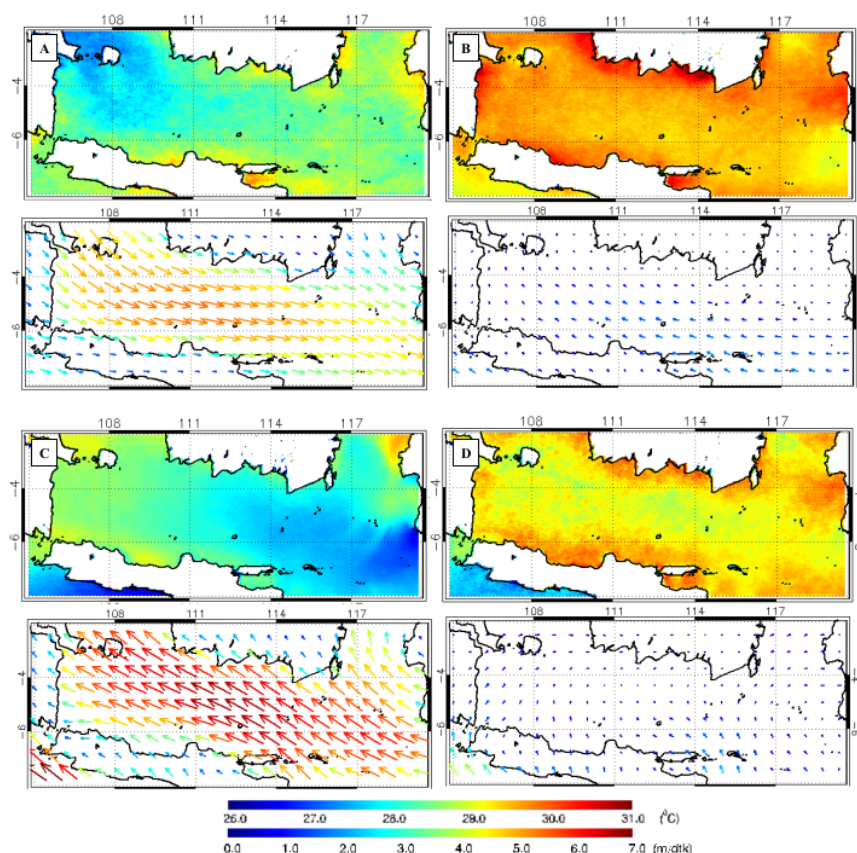


Figure 1. Climatology of SST in Java Sea in (a) NW monsoon, (b) Transition I (c) SE monsoon, and (d) Transition II with surface wind vector
(Source : NOAA Pathfinder, MODIS, and ERA Interim)

Seasonal variability mechanism of SST in the Java Sea is related to variations in wind speed [13]. The cooler (warmer) SST during NW and SE monsoon (transition I and monsoon transition) corresponds to strong (weak) wind speeds during those periods. According to Clark [14] that the strength of the monsoons that blows cause an increase in Ekman transport, vertical mass mixing, and evaporation which can affect the cooling or heating of the SST, furthermore according to Wirasatriya [15] SST variation in Java Sea was influenced by heat gain and heat loss, the mechanism of wind speed on affecting SST was through latent heat release. The stronger wind speed, the more latent heat release and the higher SST would be. Winds can carry the mass of cold water originating from Australia to Java Sea when SE monsoon and mass of cold water originating from the South China Sea to Java Sea when NW monsoon occurs [4]. In the area of the study site, the influence of the monsoon in influencing the SST is caused by mixing, this is because the Java Sea is an open sea area. This was also reinforced by Wirasatriya's research [16] that monsoon winds produce mixing in the open seas, whereas in areas along the coast, SST cooling is caused by coastal upwelling.

3.2 Effect of ENSO to the SST in Java Sea

To find out ENSO climate variability, we used the ONI index, whereas the IOD climate variability, used the DMI index. The time-series of the ENSO and IOD event over a 36-year period is presented in figure 2 which is given a purple line to determine the conditions of these two variabilities that occur at the same time.

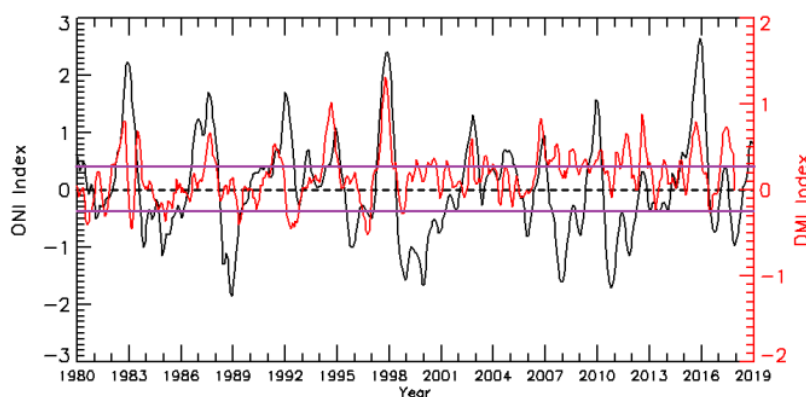


Figure 2. Time series of ONI index and DMI index for 36 years period

Increases and decreases of SST than the climatological SST, indicates that there was an interaction between the atmosphere and the ocean called anomalies. So we composed monthly SST into each event, i.e when IOD normal, negative IOD, positive IOD, ENSO normal, El Niño, and La Niña and compared to the climatological SST as shown in figure 3-6 consist of NW monsoon and SE monsoon. First, we show the conditions of ENSO and IOD when in normal conditions.

ENSO events without IOD occurrence, in NW monsoon, SST during El-Niño (La Niña) tend to be warmer (cooler), in SE monsoon, El-Niño (La Niña) tend to be cooler (warmer) as shown in figure 3. The influence of the wind speed in the SE monsoon (NW monsoon) during El-Niño (La-Niña) conditions causes the SST becomes cooler. Whereas in SE monsoon (NW monsoon) during La-Niña (El-Niño) conditions, the SST becomes warmer. This is consistent with previous study [5], that the effect of ENSO in the Java Sea depends on the season, due to the strong influence of monsoon wind variations on the variability of SST anomalies.

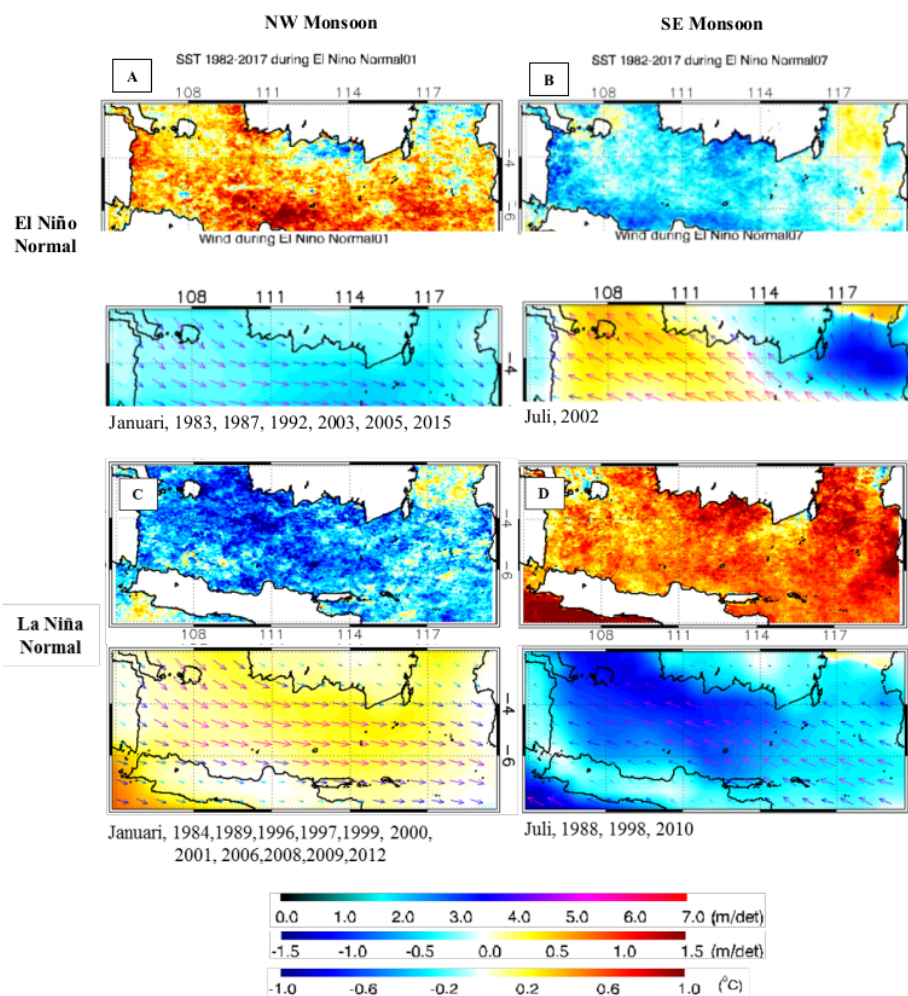


Figure 3. Distribution SST in Java Sea in condition of El-Niño when IOD normal in (a) NW monsoon, (b) SE monsoon, and La-Niña when IOD normal in (c) NW monsoon, and (d) SE monsoon with wind vector.

IOD events without ENSO occurrence as shown in figure 4, in NW monsoon and the SE monsoon, SST during positive IOD tend to be cooler, while during negative IOD in SE monsoon, SST tends to be warmer. This is consistent with the previous study [17], that during positive IOD, SST in Indonesian waters tend to be cooler than its climatological, so the waters in Indonesia have drought due to subsidence and air mass flow away from Indonesian waters, whereas, during negative IOD, SST tend to be warmer, so that the area in Indonesia will be a buildup of clouds or high convective areas, causing high rainfall due to increased evaporation [18]. The influence of stronger wind in NW monsoon and SE monsoon when positive IOD, causes SST to be cooler due to mixing in the waters, whereas weaker wind during negative IOD in SE monsoon, causes SST to be warmer.

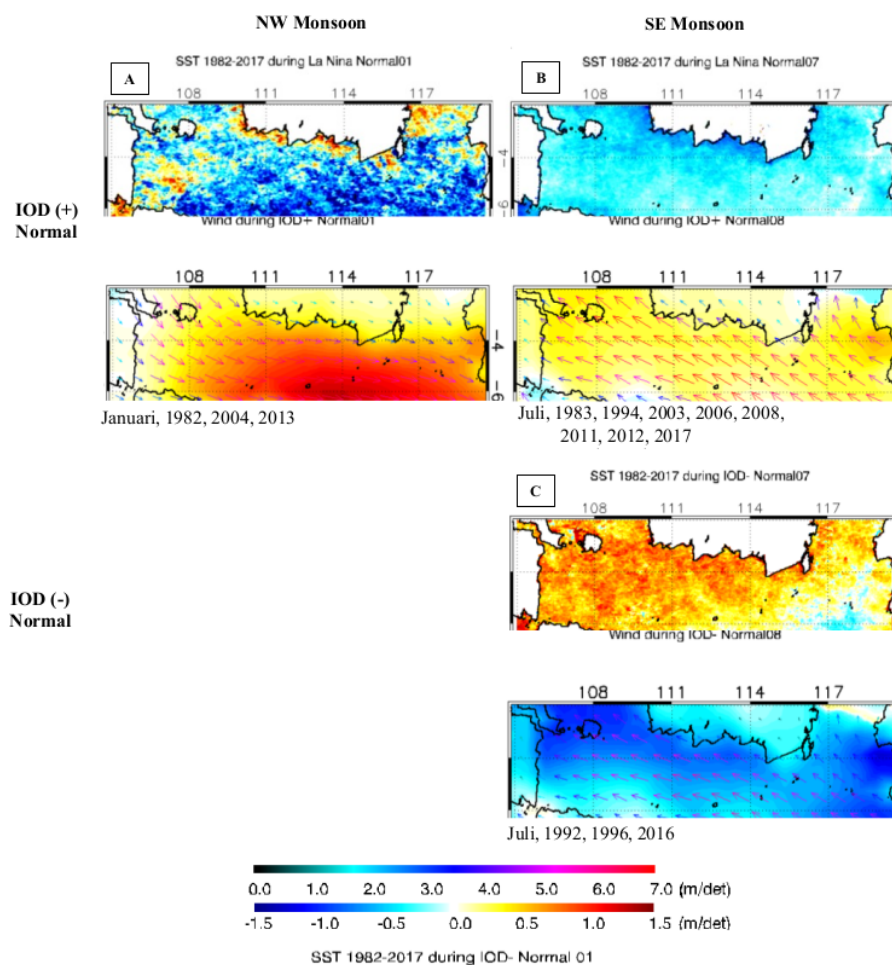


Figure 4. Distribution SST in Java Sea in condition of positive IOD when ENSO normal in (a) NW monsoon, (b) SE monsoon, and negative IOD when ENSO normal in (c) NW monsoon with wind vector.

Then we show when ENSO and IOD occur together and influence each other as shown in figure 5-6. El-Niño events when with positive IOD (figure 5) in NW monsoon (SE monsoon) SST tends to be warmer (cooler), it means that in the NW monsoon (SE monsoon) the effect of ENSO and IOD weakens (strengthens) each other. When El-Niño with IOD is negative, in the NW monsoon SST becomes warmer, while in SE monsoon, SST tends to be cooler despite there is a contribution of warm SST, it means ENSO and IOD strengthens (weakens) in the NW monsoon (SE monsoon) each other.

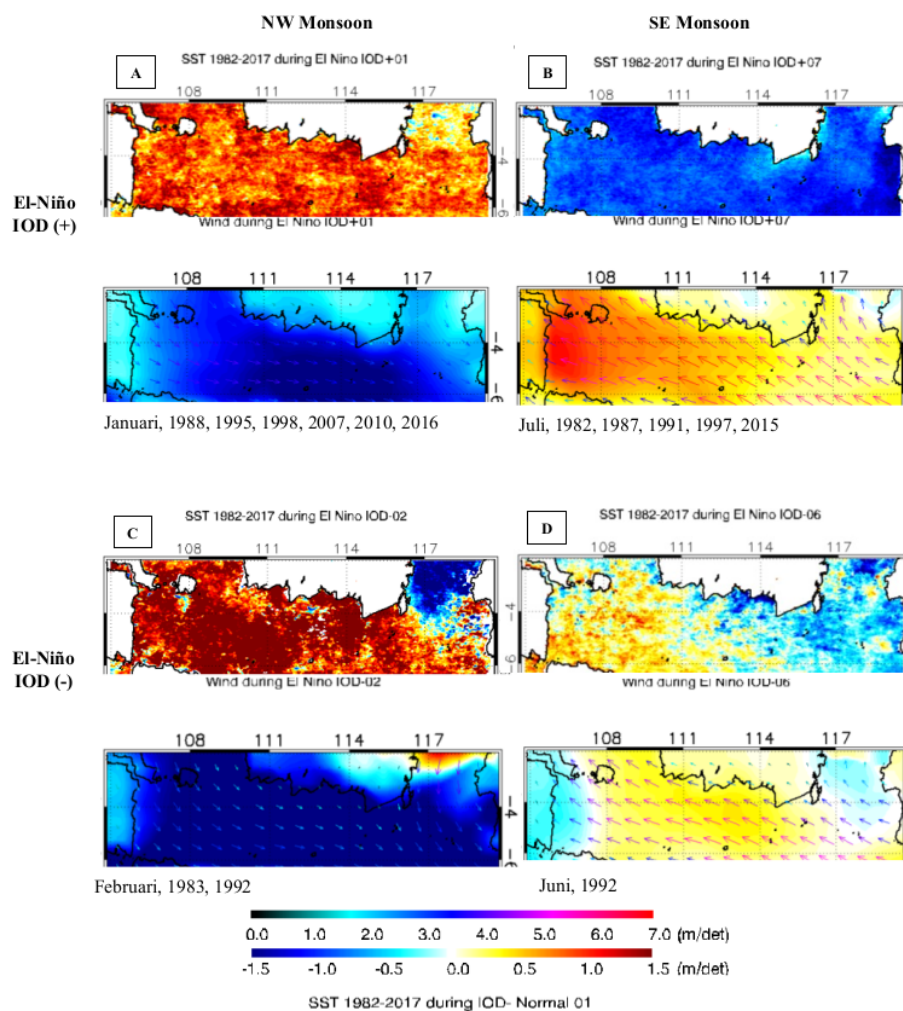


Figure 5. Distribution SST in Java Sea in condition of El-Niño when postive IOD in (a) NW monsoon, (b) SE monsoon, and El-Niño when negative IOD in (c) NW monsoon and (d) SE monsoon with wind vector.

Wind anomaly in both conditions when NW monsoon (SE monsoon) winds are weakens (strengthens) causing SST to be warmer (cooler). The influence of the contribution of El-Niño with a stronger intensity at the same time as the influence of positive IOD and negative IOD is based on data from the Australian Bureau of Climatology in 1982, 1983, 1987, 1998, 2015 that the intensity of ENSO event is stronger than the intensity of IOD event. So that the effect of ENSO appears to be more dominant than the effect of IOD, besides the influence of the wind anomaly itself causes the SST anomaly in NW monsoon is higher than SE monsoon.

The occurrence of La-Niña with positive IOD (figure 6) in NW monsoon (SE monsoon) SST tends to be cooler (warmer), it means that the effect of ENSO and IOD strengthens (weakens) each other.

Whereas when La-Niña with IOD is negative, even though it only occurs in NW season, SST tends to be colder, which means the influence of ENSO and IOD is weakened each other.

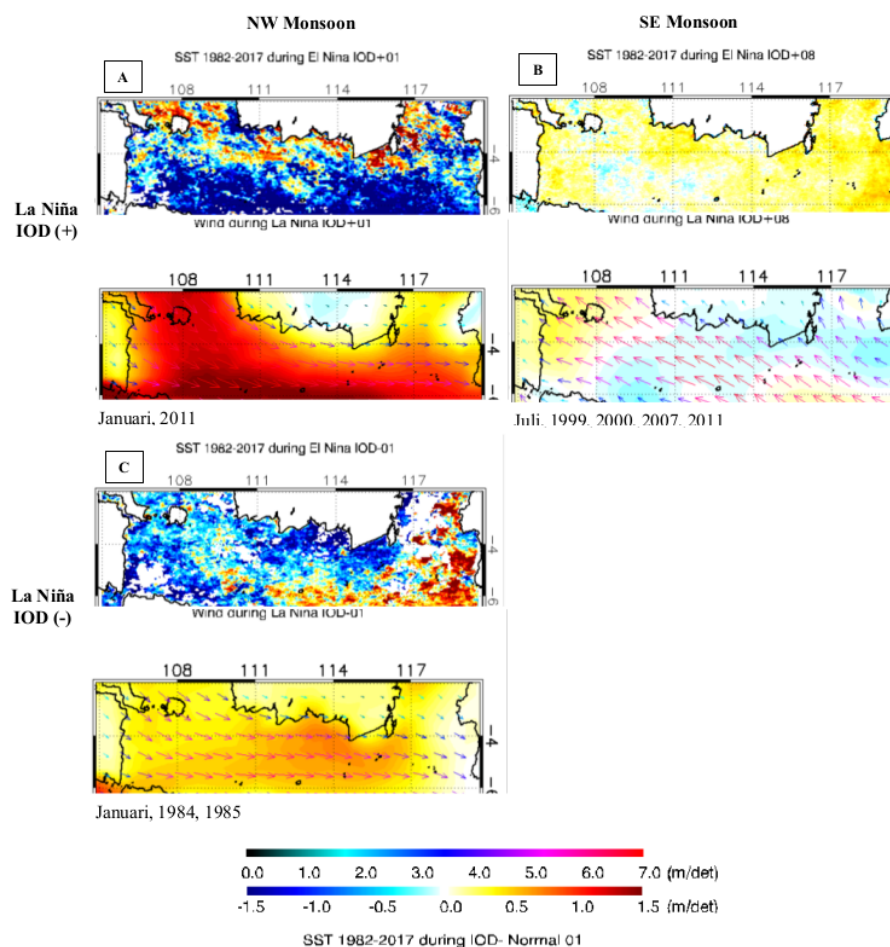


Figure 6. Distribution SST in Java Sea in condition of La-Niña when positive IOD in (a) NW monsoon, (b) SE monsoon, and La-Niña when negative IOD in (c) NW monsoon and (d) SE monsoon with wind vector.

The effect of La-Niña intensity is stronger when it occurs with positive and negative IOD events, based on data from the Australian Climatology Bureau in 1985, 1999, 2007, 2011, that in that year the ENSO intensity was stronger than the intensity of the IOD, thus causing the effect of ENSO more dominant than IOD. Wind anomalies also show their effects on SST anomalies, when NW monsoon (SE monsoon) winds blow stronger (weaker) causing SST to tend to be cooler (warmer).

Previous study suggests that the influence of ENSO is independent with IOD, but can have a significant effect [19]. In addition, ENSO can increase and decrease the frequency of IOD. IOD has a physical mechanism that is similar to ENSO but statistically does not depend on ENSO [17], and IOD events are not triggered by the presence of ENSO and thus appear independently with ENSO [20].

4. Conclusion

1. The influence of ENSO climate variability in the Java Sea depends on the season. During El-Niño conditions in the NW monsoon (SE monsoon), SST becomes warmer (cooler), during La-Niña conditions in NW monsoon (SE monsoon) SST becomes cooler (warmer). In contrast to the IOD, IOD climate variability in the Java Sea does not depend on the season, during positive IOD conditions in NW monsoon and SE monsoon, SST becomes cooler, during IOD negative condition SST becomes warmer. While the influence of ENSO with IOD that occurs together, its influence can be determined based on the intensity of the anomalous strength of each of the climate variability.
2. The mechanism of ENSO and IOD climate variability in influencing SST is related to wind anomalies.

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