Differential Influences of Teleconnections from the Indian and Pacific Oceans on Rainfall Variability in Southeast Asia

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Abstract: This study investigates the individual and combined impacts of El Niño and the positive Indian Ocean Dipole (IOD) on the Southeast Asia (SEA) rainfall variability. Using composite and partial correlation techniques, it is shown that both inter-annual events have individually distinct impacts on the SEA rainfall anomaly distribution. The results showed that the impacts of the co-occurrence of El Niño and IOD events are significant compared to the individual effects of pure El Niño or pure IOD. During June-July-August and September-October-November, the individual impacts of the pure El Niño and IOD events are similar but less significant. Both events caused negative impacts over the southern part of SEA during June-July-August (JJA) and propagated northeastward/eastward during September-October-November (SON). Thus, there are significant negative impacts over the southern part of SEA during the co-occurrence of both events. The differential impacts on the anomalous rainfall patterns are due to the changes in the sea surface temperature (SST) surrounding the region. Additionally, the differences are also related to the anomalous regional atmospheric circulations that interact with the regional SST. The anomalous Walker circulation that connects the Indian Ocean and tropical Pacific Ocean also plays a significant role in determining the regional anomalous rainfall patterns.

Keywords: interannual variability; positive IOD; El Niño

1. Introduction

Southeast Asia (SEA) lies in between two major oceans, the Pacific and the Indian Ocean, which both play an important role in the world’s climate variability. The land-ocean-atmosphere coupling system on these oceans may change the atmospheric and oceanic circulations that affect local climatic conditions, even in remote areas. Various aspects of the El Niño-Southern Oscillation (ENSO) phenomenon have been studied due to their great socio-economic and community impacts [1–8]. This also applies to the large-scale inter-annual phenomenon which originates from the tropical Indian Ocean, known as the Indian Ocean Dipole (IOD) [9–12]. The impacts of the IOD are also not limited to the equatorial Indian Ocean, but appear globally through changes in atmospheric circulation [13]. Despite the potential impact on the regional climate in SEA, previous studies of the impacts of the IOD over this region are rather limited [10,13–15].
Knowledge of the coexistence of the ENSO and IOD events, mainly based on statistical research, has raised some interesting issues related to the existence/nonexistence of the IOD and any dependency/non-dependency with the ENSO [16–29]. The correlation between the IOD (Dipole Mode Index (DMI)) and the El Niño (Niño3 index) is 0.53 during the peak of the IOD season, which is in September-October-November (SON). This is a significant correlation which could mean that the IOD event exists as part of the ENSO [30,31]. However, according to Yamagata et al. [32], these statistics could also be interpreted as suggesting that only a third of IOD events are associated with ENSO events. In another study, Vinayachandran et al. [33], stated that only 50% of IOD events have coexisted with ENSO during the past 100 years. Some of the positive IOD events that evolved without the presence of the El Niño occurred in 1961 and 1967 [10,32]. Several studies were also conducted either using observed data or an ocean/atmosphere simulation model to discuss various other aspects related to ENSO and the IOD phenomenon [13,33–35]. Ashok et al. [34] used observations of sea surface temperature (SST) data from 1871 to 1998 and found that most of the IOD exists without the presence of the El Niño. However, Shinoda et al. [35] used data from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project and a general circulation model to investigate the remote forcing on SST variations in the Indian Ocean during the presence of ENSO, and they found that there was an “atmospheric bridge” linking the two oceans.

In addition, several past studies have also successfully reproduced IOD and ENSO events using coupled general circulation models (CGCMs) [36–44]. Most of these studies were able to detect both IOD and ENSO events in their models. Wu and Kirtman [45] also used CGCMs to understand the impact of the Indian Ocean on ENSO variations. They found that the variations in ENSO reduced significantly when the Indian Ocean was not coupled with the atmosphere. Baquero-Bernal et al. [31], on the other hand, could not find the coupling mode in the Indian Ocean without the presence of ENSO. In their model study, Lizuka et al. [46] found that the IOD and ENSO events only had a weak correlation. A more recent study by Wang et al. [27] suggested that ENSO is not fundamental to the existence of the IOD, as the coupled model simulation can reproduce the most salient observed features of the IOD even without ENSO. From a different research perspective, the need to understand the teleconnections of ENSO and the IOD, either their individual or combined influence, is also important [16,18,47,48], as their regional influence on society is greater than the coupling phenomenon itself [32].

Juneng and Tangang [4] have discussed SEA ENSO-related rainfall anomalies that evolve northeastward from the beginning phases of the El Niño in summer to its decaying phases in the spring season of the following year. The northeastward evolution is modulated by two anti-cyclonic systems over the south Indian Ocean and the north western Pacific, respectively. The southern part of SEA, such as Sumatra, Java Island, Sulawesi, and southern Borneo, are affected significantly during summer, while effects on other areas, such as northern Borneo and the southern Philippines, are more pronounced during the winter season. However, this study did not separate the events of pure El Niño and those co-occurring with IOD events. Therefore, there is a lack of information on the differential of teleconnections and possible impacts on SEA rainfall variability. The El Niño event coexisted with a positive IOD event in 1997/98 [10,34]. During this year, Malaysia was strongly impacted, experiencing serious drought conditions that caused a severe haze episode [5]. Aside from this, there were also years of El Niño without an IOD event; these individual appearances also had different impacts on the SEA rainfall variability [47]. On the other hand, the IOD phenomenon has also been proven to have different impacts to those of El Niño events [10,15,37,48]. Rao et al. [49] and Vinayachandran et al. [33] emphasized the positive IOD in their study, due to the significant impacts it have in various areas either individually or together with the El Niño. Positive IOD is characterized by cooler than normal water in the eastern tropical Indian Ocean and warmer water than normal conditions in the tropical western Indian Ocean [10,15,50]. The wind direction is opposite to the norm, from westerlies to easterlies. These changes cause convection to move westward, which usually occurs in warmer areas in the eastern Indian Ocean, and brings heavy rainfall to eastern Africa and Sri Lanka and severe drought/forest fires to Indonesia and Australia [13,39,50–53]. The IOD atmosphere-ocean coupling

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is phase-locked to a seasonal cycle [10,50], which develops in spring, peaks in autumn, and decays during the boreal winter. Coupling feedback between the SST, wind, upper ocean heat content, and rainfall leads to the development of a positive IOD [32].

Therefore, this paper will focus on understanding the impacts of the influence of a positive IOD and the El Niño, either individually or combined, on the SEA rainfall variability. The second section of this paper will discuss the materials and methods used, continuing on to a discussion of rainfall distribution related to the El Niño and IOD events in Section 3. Section 3 also will discuss the SST and atmospheric circulation related to these events and, finally, Section 4 presents a summary.

2. Materials and Methods

Observation data from 1960 to 2018 are used in this study. The monthly atmospheric components at a resolution of 2.5° × 2.5°—i.e., horizontal winds and vertical velocity—were obtained from the NCEP/NCAR Reanalysis 1 Project [54]. The moisture flux and its divergence were calculated from the NCEP/NCAR. HadISST of the United Kingdom Meteorological Office (UKMO) with a resolution of 1.0° × 1.0° is also used [55]. In addition, high-resolution rainfall data (0.5° × 0.5°) were obtained from the Global Precipitation Climatology Centre (GPCC) [56]. The Dipole Mode Index (DMI) is defined based on Saji and Yamagata [13], in which the strength is represented by the anomalous SST differences between the tropical western Indian Ocean (50° E–70° E, 10° S–10° N) and the tropical south-eastern Indian Ocean (90° E–110° E, 10° S–Eq) [10]. The El Niño event was identified using the Niño3.4 index, which is represented by the area-averaged SST anomalies from 5° S–5° N and 170°–120° W [55]. Both the DMI and Niño3.4 were calculated from the HadISST. IOD is a seasonal phase locking phenomenon which appears around June, develops in the following month, and peaks in October [10,11,33,57–59]. IOD years are defined as years when any of the months in September-October-November (SON) have DMI values equal to or larger than 0.5 °C. There are two types of timing onset for El Niño: one is the spring type and the other is the summer type [60,61]. The El Niño events are phase-locked and peak in boreal winter (e.g., [1]). Therefore, we define all the El Niño years when the Niño3.4 index is equal to or more than 0.5 °C crossing the months of June to February the following years. Table 1 lists the pure El Niño years, pure IOD years, and the co-occurrence of both events for composite analysis. A pure El Niño event is defined as the occurrence of El Niño without a positive IOD event, while a pure IOD event is defined as the occurrence of a positive IOD without an El Niño event. Overall, from 1960 until 2018 there were five events of pure El Niño, five pure positive IOD events, and seven events of El Niño coexisting with a positive IOD. For simplicity, a positive IOD is referred to as IOD throughout this study.

| Pure El Niño | Pure IOD | Co-Occurrence of El Niño and IOD |
|--------------|----------|---------------------------------|
| 1965/66      | 1961     | 1963/64                         |
| 1969/70      | 1994     | 1972/73                         |
| 1991/92      | 2006     | 1982/83                         |
| 2004/05      | 2011     | 1987/88                         |
| 2009/10      | 2012     | 1997/98                         |
|              |          | 2002/03                         |
|              |          | 2015/16                         |

The partial correlation analysis was also used in this study to determine the impacts of the El Niño and IOD events as in Saji and Yamagata [13]. Partial correlation techniques isolate other global effects such as El Niño effects from the IOD and vice versa—for example, the partial correlation between the anomalous rainfall and Niño3.4—while isolating the effect caused by the correlation between anomalous rainfall and DMI. The partial correlation definition follows:
\[ r_{13,2} = \frac{(r_{13} - r_{12} \cdot r_{23})}{\sqrt{(1 - r_{12}^2)} \cdot \sqrt{(1 - r_{23}^2)}} \]  

where \( r_{13} \) refers to the correlation between the first global effect and the anomaly field, \( r_{12} \) is the correlation between the two global effects, and \( r_{23} \) is the correlation between the second global effect and the anomaly field.

3. Results and Discussion

3.1. Anomalous Rainfall Distributions

Figure 1 shows the rainfall anomaly composite for the events listed in Table 1. The left panel represents the anomalous rainfall distribution of the co-occurrence of the El Niño and IOD events, the middle panel depicts the pure El Niño event, and the right panel shows the pure IOD event. Generally, Figure 1 shows that the negative impacts of the individual event are not as significant as those from the co-occurrence of both events.

During the co-occurrence of the El Niño and IOD events (left panel), the rainfall anomaly distributions and northeastward evolutions were shown to resemble the analysis of Juneng and Tangang [4]. During the co-occurrence of both events in the summer boreal season of June-July-August (JJA), most of the southern part of the SEA region experienced a significant dry season, especially over Sumatra, the Java Islands, southern Borneo, and Sulawesi (Figure 1a). In the following season of SON, the dry area shifted northeastward and intensified. This is because at this stage, although the El Niño phenomenon was still in its developing phase, the IOD had already reached its peak, and thus significant negative impacts are depicted over the southern and eastern part of SEA, including the east coast of Peninsular Malaysia (Figure 1b). The significant dry area continued to shift northeastward during the December-January-February (DJF) season and took place over areas including northern Borneo, Celebes, and the Philippines (Figure 1c). This is consistent with Mahmud [62], where the impact of the El Niño event became pronounced over east Malaysia compared to Peninsular Malaysia due to the influence of the IOD. In the March-April-May (MAM) season the following year, the significant dry condition continued to shift further northeastward, leaving the southern part of SEA with wetter conditions (Figure 1d). The northern part of Peninsular Malaysia was also found to be significant in this season. Generally, there are patches of negative impacts that can be seen over the Indochina region (Vietnam, Laos, Cambodia, southern Thailand, Peninsular Malaysia) throughout the four seasons, but they are not significant.

On the other hand, the occurrence of El Niño without an IOD event, still illustrated the northeastward evolution, but the negative impacts were not significant for most of the season compared to that of the combined events (Figure 1e–h). During the JJA season, the composite of pure El Niño events showed the same rainfall conditions as in the combined events, but less significant (Figure 1e). During the following season, there was not much difference in the rainfall pattern from the previous season, but with slight shifts northeastward (Figure 1f). However, during the DJF season the driest area shifted further northeastward, withdrawing from the southern part of the SEA regions, such as Sumatra, the Java Islands, the Celebes, and southern Borneo, and being replaced with patches of significantly wetter than normal conditions (Figure 1g). The rainfall pattern remained in most of the region during the MAM, season but with less intensity (Figure 1h). Northern Sumatra and Peninsular Malaysia experienced negative impacts during this season.
Figure 1. The composite of anomalous rainfall for the events listed in Table 1. The hatched area indicates significance at the 95% level. (a–d) Co-occurrence of the conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the season of June-July-August (JJA), September-October-November (SON), December-January-February (DJF), and March-April-May (MAM). Unit is mm month$^{-1}$.

During the IOD without El Niño events, the negative impacts were also less significant throughout the year (Figure 1i–l). However, the first two seasons also depicted an eastward/northeastward propagation of the negative impacts as in the pure El Niño event. During JJA, the southern part of SEA experienced drier conditions, and in the following season the dry condition covered the eastern and southern area of SEA (Figure 1i,j). According to Ratna et al. [63], rainfall tends to decrease over the northwestern Java, especially during dry season (August-October). Drought condition will occur when the IOD event co-occurs with the El Niño event. This is consistent with the appearance of patches of significant negative rainfall over northwestern Java, as shown in Figure 1i,j. Generally, both pure El Niño and IOD events have the same impacts over SEA during the JJA and SON seasons. This explains the significantly negative impacts on SEA when both phenomena occur simultaneously in these two
seasons. However, drastic changes in the SEA rainfall distributions occurred during the other two following seasons. Wetter conditions took place over most of the SEA region during the DJF and MAM seasons (Figure 1k,l). It can be concluded that both inter-annual events have distinct impacts on the SEA rainfall anomaly distribution. ENSO-related rainfall will evolve northeastward from JJA to the MAM season, while IOD-related rainfall will move eastward/northeastward in the first two seasons with less significant negative impacts. However, depending on the season, the combined effects of both events may cause severe drier conditions over the SEA region compared to the other two individual events.

We have plotted another rainfall distribution pattern using the partial correlation technique between the rainfall anomalies and the Niño3.4 (DMI) index after removing signals from the DMI (Niño3.4), also known as the pure El Niño (pure IOD) event in this study (Figure 2). The results show consistency with Figure 1, with clearer visuals of the individual impacts of each phenomena on the SEA rainfall pattern. After removing the IOD signals, there was a significant negative correlation that evolved northeastward during the pure El Niño event from JJA to the MAM season (Figure 2, left panel). During the JJA season (Figure 2a), pure El Niño events were particularly prominent, which caused anomalously dry conditions throughout Indonesia; this is consistent with Supari et al. [8]. The significant negative loading shifted northeastward in SON and covered the eastern part of the SEA region (Figure 2b). An apparent eastward/northeastward movement of the negative loading at the first two seasons of JJA and SON was also shown in the IOD event after removing the El Niño signal (Figure 2e,f). The features of the pure El Niño and IOD events during the SON season are also consistent with Saji and Yamagata [13] and Ratna et al. [63], where the El Niño and IOD events had the same impacts on Indonesia, leading to an atmospheric anomaly and subsequently to a severe drought over the region. Hamada et al. [14] also notes that the IOD event caused drier conditions in the western Java Sea during this season, which is consistent with Figure 2f. This explains the severe drought over that region during the co-occurrence of both events in the SON season (Figure 1b). During the DJF and MAM seasons, the El Niño plays a major role in the dry conditions at the northern part of the equatorial region (Figure 2c,d), while the IOD terminates at these seasons and leaves most of the region with wetter than normal conditions (Figure 2g,h). According to Juneng and Tangang [4], the effects of the El Niño on the SEA rainfall distribution are varied due to the northeastward evolution from JJA to MAM, which modulated by the two anti-cyclonic systems over the south Indian Ocean and northern western North Pacific (WNP). The southern part of SEA, such as Sumatra, Java Island, and southern Borneo, are affected significantly during JJA, while the other areas, such as northern Borneo and the southern Philippines, are more pronounced during the DJF season.

During the co-existence of both events, the western Pacific Ocean depicts significantly cooler boomerang-shaped SST flanking warmer water in the central Pacific Ocean, which relates to the El Niño signals during the JJA season. On the other hand, the IOD features are apparent over the Indian Ocean, with cooler (warmer) water over the eastern (western) part of the Indian Ocean (Figure 3a). During the SON season, where the IOD reaches its matured phase, a significant dipole pattern appears over the Indian Ocean and the southern arm of the boomerang-shaped SST, while its northern arm diminishes from the previous season. It was also noticed that the southern arm of the boomerang-shaped SST enters the west coast of Australia (Figure 3b). The cooler water from the Java sea and warmer water over the western Indian Ocean form a significant dipole, which is related to the IOD event over the Indian Ocean [10,33]. According to Clarke and Liu [64] and Meyers [65], the ENSO signal is able to enter the eastern Indian Ocean from the western Pacific Ocean through the coastal waveguide around the Australian Continent. This suggests that the SST over the eastern Indian Ocean near the west coast of Australia is affected by ENSO during the SON season, which is known as the Clarke–Meyers effect. However, according to Vinayachandran et al. [33], this phenomenon differs from the cooling water over Sumatra which relates to the basin-wide IOD phenomenon that involves equatorial ocean dynamics by horizontal wind in the equatorial region. Wang et al. [66] also argued that the interaction between the atmosphere and ocean is important in maintaining the features over the southern Indian
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Ocean and Java seas. At the same time, significantly warmer than normal conditions over the SCS are also observed (Figure 3b). Notice that the IOD feature is only visible during JJA and SON because this coupling mode is phase-locked to these two seasons [10,11,33,57–59].

Figure 2. [Left panel] (a–d) Partial correlation between the Global Precipitation Climatology Centre (GPCC) rainfall anomalies and Niño3.4 after removing the IOD signal, [Right panel] (e–h) partial correlation between the GPCC rainfall anomalies and DMI index after removing the Niño3.4 signal for the season of JJA, SON, DJF, and MAM. The hatched area indicates significance at the 95% level. Unit is mm month$^{-1}$.
3.2. Sea Surface Temperature and Atmospheric Circulation

3.2.1. Anomalous Regional Sea Surface Temperature

Figure 3 examines the composites of regional SST anomalies which relate to the rainfall anomalies over the SEA region during the three events, as listed in Table 1. According to Juneng and Tangang [4], the ENSO-induced SST anomalous conditions over the western Pacific, Java Sea, Indian Ocean, and South China Sea (SCS) are very important to determine the SEA rainfall anomaly. They also argued that the northeastward evolution of the SEA rainfall anomalies is concomitant with the evolution of ENSO-related SST anomalies.

Figure 3. The composite of anomalous sea surface temperature (SST) for the events listed in Table 1. The hatched area indicates significance at the 95% level. (a–d) Co-occurrence of the conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the seasons of JJA, SON, DJF, and MAM. Unit is degrees Celsius.

The regional SST anomaly conditions changed drastically during the DJF seasons (Figure 3c). This is related to the transition of the monsoon season from the southwest to northeast monsoon,
which the positive feedback between the southern Indian Ocean anticyclonic and the SST dipole is dependent on [66]. Therefore, the warmer regional SST conditions are due to the negative feedback between the background and anomaly circulations, and also the weakening of the boomerang-shaped SST southern arm. Most of the cooler water during the SON season was replaced with warmer water in the DJF season, particularly over the Indian Ocean, SCS, and Java Sea. Significantly cooler water in the western North Pacific (WNP) indicates the strengthening of the northern arm of the boomerang-shaped SST [4, 66]. Besides this, the IOD event also decays/terminates during this season (Figure 3c). Therefore, compared with the individual events (Figure 3g,k), the El Niño signal pattern is more pronounced in the combined events compared to that of the IOD signal. However, the cooperative signals from both events enhanced the warmer and cooler than normal water conditions significantly. The SST anomalies pattern did not change much during the MAM season, when its intensity reduced (Figure 3d).

The anomalous SST pattern during the pure El Niño events depicts a different pattern and less significant intensity from that of the combined events, especially over the Indian Ocean and WNP. During the JJA season, most of the SST anomalies surrounding SEA experience cooler conditions (Figure 3e). Without the IOD event, there is no positive dipole over the Indian Ocean and no significant connection between the Pacific Ocean and Indian Ocean via the Java Sea. The intrusion of cooler water to western Australia also did not appear. During the SON season, the regional SST anomaly pattern is not much different from the previous season. However, the development of warmer water over the northern Indian Ocean and SCS can be observed. Besides this, the cooler southern arm of the boomerang-shaped SST is enhanced and becomes more significant (Figure 3f). Warmer water occurs in the DJF season over the Indian Ocean, Java Sea, SCS, and the northwestern Pacific. This condition is depicted in combined events but is less/not significant. This is expected, since during DJF the IOD event has decayed (Figure 3g). The strengthening of the northern arm of the boomerang-shaped SST can be seen through the significantly cooler water over the WNP. Warmer water over SCS becomes significant during the MAM season (Figure 3h).

On the other hand, during the pure IOD event of the JJA and SON seasons, the waters surrounding SEA, such as the eastern Indian Ocean, SCS, and the Java sea, are dominated by cooler water and circled by warmer water over the western Indian Ocean and WNP. Cooler water in the eastern and warmer water over the western Indian Ocean indicate IOD features with the absence of the cooler boomerang-shaped SST over the WNP during these two seasons (Figure 3i,j). According to Ashok et al. [34], the cooler than normal conditions of SST off Sumatra and Java during these two seasons cause anomalous subsidence over the Maritime Continent, decreasing the rainfall over Indonesia. The dipole features over the Indian Ocean weakened and disappeared in the following DJF and MAM seasons due to its termination, leaving most of the water surrounding SEA to became warmer (Figure 3k,l). During these seasons, both individual events were dominated by warmer SST conditions, especially over Indian Ocean, SCS, and Java Sea; thus, significant warmer than normal conditions happened during the co-occurrence of both events.

Figure 4 shows the partial correlation between the SST anomalies and the El Niño (IOD) after removing the IOD (El Niño) signal. The results reveal consistent information with Figure 3 (middle and right panel). Generally, the ocean features over the WNP are similar to those of the combined events. However, the IOD features over the Indian Ocean completely disappear. The southern arm of the boomerang-shaped SST is strong during the JJA season and strengthens during the SON season (Figure 4a,b). The intrusion of cooler water from the southern arm of the boomerang-shaped SST to western Australia can be seen, but not to the eastern Indian Ocean via the Java Sea. In the following season, the pure El Niño event replicates the combined event ocean features. The whole Indian Ocean, SCS, and Java Sea showed a significant positive loading. The cool pool on the east and the warm pool on the west form a significant dipole over the WNP (Figure 4c). This feature is related to the strong anti-cyclonic system over the WNP during the DJF season [4,66]. The pattern remains with lesser intensity in the MAM season (Figure 4d).
In contrast, after removing the El Niño signal from the IOD event, the cooler boomerang-shaped SST over the western Pacific did not appear and was replaced with warmer water. On the other hand, significant IOD features were observed over the Indian Ocean (Figure 4e,f). Without the co-occurrence of both events, the Java Sea still depicted significantly cooler water; however, the connection between these two basins did not occur. As the IOD event is phase-locked to the JJA and SON seasons, there was no significant dipole and negative loading monopolized the Indian Ocean during the DJF season.
Conversely, the western Pacific showed a significant positive correlation. The pattern remained, with a slightly stronger positive (negative) correlation over the WNP (Indian Ocean) in the MAM season (Figure 4h). The distinct regional SST anomaly distribution among the three events played an important role in different impacts over the SEA rainfall anomalies, apart from the large-scale effects through local air–sea interactions and walker circulations.

3.2.2. Anomalous Atmospheric Circulation

Figure 5 shows the anomalous regional low-level wind circulation, which is consistent with the regional SST anomaly pattern. In the JJA season, during the co-occurrence of the El Niño and IOD events, the low-level wind appeared to be strong and significant over all the regions. The low-level wind anomalies at the north of the ridge were dominated by westerlies, while at the south they were dominated by southeasterlies/southerlies (Figure 5a). Over the Java Sea, the average monsoonal background flow during this season was southeasterly, therefore the anomalous easterlies/southeasterlies caused cooling evaporation in that region. The anomalous SST over the Indian Ocean is generated from the strong easterly winds that caused thermocline elevation (suppression) in the east (west) of the Indian Ocean, which developed dipole features. This also resulted in the positive feedback of SST evaporative cooling, and thus the significantly cooler water near Sumatra (Figures 3a and 5a). Consistent with the low-level wind anomalies, Figure 6a shows that the anomalous moisture is transported away from the Bay of Bengal, SCS, and the Maritime Continent towards the WNP. During the event of the El Niño coexisting with the IOD, almost the entire region of SEA, especially over the southern part of the Maritime Continent, experienced a divergence of moisture flux anomalies, which is consistent with the drier conditions over that area (Figures 1a and 2a). In addition, Juneng and Tangang [4] also found that the area is under high outgoing longwave radiation (OLR). This is also consistent with the vertical velocity anomalies at 500 mb levels, which show significant descending air (red color) over the Maritime Continent, mainly in the southern part (Figure 7a).

The anomalous low-level wind circulation patterns during the pure El Niño event were relatively weak, especially over the Indian Ocean, SCS, and surrounding areas (Figure 5e). The differences in the SST anomalies over the WNP are generated by the significant anti-cyclonic system. Besides this, the weak anti-cyclonic system over the southern Indian Ocean formed weak SST anomaly differences between the southwest Indian Ocean (warmer water) and west of Java Island (cooler water) (Figures 3e and 5e). Consistent with the low-level wind anomalies, Figure 6 shows the anomalous low-level moisture flux and its divergence. The high-pressure anti-cyclonic system over the southern Indian Ocean has brought away the moisture from Java Island and Sumatra, which causes drier conditions (Figures 1e and 6e). The significant westerlies over the WNP are related to the elongated cyclonic system above it, transporting moisture away from Borneo Island, hence causing drier conditions (Figures 1e and 6e). The vertical velocity anomaly pattern at 500 mb is also consistent with the pattern of rainfall anomalies. Descending air over the eastern Maritime Continent, which originated from the eastern/central Pacific Ocean, has suppressed the convection processes and led to drier than normal conditions over that region (Figures 1e and 7e).

On the other hand, the low-level wind during the pure IOD events was strong and significant, particularly over the Indian Ocean and the Maritime Continent compared to that over the WNP (Figure 5i). The average monsoonal background flow during the JJA season over the Java Sea is southeasterly, therefore the anomalous easterly/southeasterly wind causes cooling evaporation over that area (Figures 3i and 5i). The equatorial wind direction changed from westerlies to easterlies during the pure IOD events, which led to cooler SST conditions in the east and warmer SST conditions in the west of the Indian Ocean. According to Yamagata et al. [67], the surface wind changes are associated with the basin-wide Walker circulation anomalies. The surface wind changes also caused thermocline elevation in the east and thermocline suppression in the central and western Indian Ocean, forming the dipole features. Since the southeasterly monsoonal background wind along the Java coast gets stronger during the IOD events, the anomalous coastal upwelling process also causes further cooling in the
eastern Indian Ocean. During these events, the Walker circulation that connects the Indian Ocean and the eastern Pacific Ocean does not exist due to the absence of the El Niño signal [67]. In addition, the easterly/southeasterly wind also contributes to the anti-cyclonic system in the Bay of Bengal (Figure 5). Consistent with the low-level wind anomalies, the Maritime Continent experienced drier conditions due to significant easterly/southeasterly wind that transported moisture away from the southern part of SEA, especially over Sumatra and Java Island, to the Indian Ocean (Figures 1i and 6i). This is also consistent with the descending air motions with a 500 mb level vertical velocity anomaly over the Maritime Continent, especially on the southern part (Figure 7i).

Figure 5. The composite of anomalous low-level wind at 850 mb for the events listed in Table 1. The bolded vector with a larger arrowhead indicates significance at the 95% level. (a–d) Co-occurrence of the conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the seasons of JJA, SON, DJF, and MAM. Unit is ms$^{-1}$. 
Figure 6. The composite of vertically integrated moisture flux (vectors) (kg m$^{-2}$ s$^{-1}$) and moisture flux divergence (shaded) (kg m$^{-2}$ s$^{-1}$) anomalies for the events listed in Table 1. The hatched and bolded vector indicates significance at the 95% level. (a–d) Co-occurrence of the conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the seasons of JJA, SON, DJF, and MAM.
Figure 7. The composite of the vertical velocity anomaly at 500 mb for the events listed in Table 1. The hatched area indicates significance at the 95% level. (a–d) Co-occurrence of conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the seasons of JJA, SON, DJF, and MAM. Unit is Pa s$^{-1}$.

In the SON season, the co-occurrence of the El Niño and IOD events showed strong and significant low-level wind anomalies almost over all the regions, in which easterlies dominated the southern part of 15° N latitude, while westerlies dominated the northern part of that latitude (Figure 5b). Evolving from the previous season, there are three anti-cyclonic systems associated with this event, which are over the southern Indian Ocean, the Bay of Bengal, and the Philippines. The strong anti-cyclonic system over the southern Indian Ocean is the strengthening of the system from the previous season,
and the other two anti-cyclonic systems are formed from the previous extended ridge over the region (Figure 5a,b). The significant average monsoonal background wind and the low-level wind anomalies over the Java Sea favor the positive feedback of evaporative cooling over the area. In addition, during this event, the southern arm of the boomerang-shaped SST became stronger and spread to the west coast of Australia [4]. The anomalous southeasterlies near Sumatra were strengthened by the existence of an anti-cyclonic system in the Indian Ocean. The strong wind favored shore upwelling and vertical mixing processes, resulting in the strong positive feedback of SST evaporative cooling, and thus significantly cooler water near Sumatra (Figures 5b and 6b). The mechanism also suppressed the thermocline in the western Indian Ocean and formed a significant dipole related to the IOD events, with the cooler pool located at the east of the anti-cyclonic center and the warmer pool on its west. Consistent with this, most of the moisture flux anomalies were transported from the Maritime Continent and the oceans nearby the Indian Ocean, while the moisture flux from the northern SCS, northern Borneo, the Philippines, and the WNP is brought to the western equatorial Pacific. Most of SEA experienced moisture flux divergence, except northern Sumatra and the west coast of Peninsular Malaysia, which lies in the convergence area [4,68] (Figures 1b, 5b and 6b). A significant downward air motion over SEA is also consistent with the significant negative rainfall conditions over the region (Figure 7b).

There are distinct differences between the low-level wind anomalies during the pure El Niño events and the co-occurrence of the El Niño and IOD events, particularly over the Indian Ocean (Figure 5b,f). The anti-cyclonic system anomalies over the southern Indian Ocean that had existed in the previous season became stronger. The easterly/southeasterly anomaly winds dominated the southern part of 10° N latitude. Apart from this, the anti-cyclonic system over the WNP produced significant northwesterly/westerly anomalous winds. Consistent with the low-level wind anomalies, Figure 6f shows that most of the moisture at the south of the equator was transported to the Indian Ocean and the western Pacific Ocean. The anti-cyclonic over the WNP causes drier conditions over the northeastern part of SEA, such as northern Borneo and the Philippines (Figures 2f and 5f). The downward air motion is also consistent with the negative rainfall anomaly patterns, which shifted northeastward (Figures 2f and 7f).

Conversely, without the El Niño signal, the low-level wind anomalies still depict significant circulation over all the region, except over the WNP (Figure 5j). As previously mentioned, the cooler condition of the Java Sea is related to the positive feedback processes of evaporative cooling by the background flow and low-level wind anomalies. Therefore, during the pure IOD events, the easterly wind anomalies are shown to be strong, thus the cooler SST conditions are significant (Figures 3j and 5j). The dipole formation associated with the IOD events in the southern Indian Ocean also demonstrated Bjerknes [69] mechanisms. The significant anomalous anti-cyclonic system over the Bay of Bengal remains from the previous season, even without the El Niño signals (Figure 5i,j). The two anti-cyclonic systems over the northern and southern part of Indian Ocean cause dryer conditions in the Maritime Continent. The easterly wind at the south of the equator, which is also part of the two anti-cyclonic systems, transported away the moisture from the area at the south of the equator to the Indian Ocean, while the northern Indochina region received moisture from the Bay of Bengal (Figures 1j, 5j and 6j). Ratna et al. [63] also agreed that there is strong divergence over SEA that causes a negative rainfall anomaly during the positive IOD events which is modulated by the strong easterly winds over the southwestern region of Indonesia. The divergence over the Indonesia region is due to the IOD-induced cold SST anomaly and converges over the western Indian Ocean due to a warm SST anomaly there. This is also consistent with Hamada et al. [14], who asserted that the cooler SST anomaly surrounding SEA leads to surface divergence, decreases in the lower atmospheric water vapor, and the suppression of rainfall over Java. The vertical velocity anomalies at the 500 mb level also showed ascending air (convection enhancement) near Sumatra and significant descending air (convection suppression) over the southern part of SEA. (Figures 1j and 7j).

During the DJF season, the circulation of the low-level wind anomalies during the event was dominated by a strong anti-cyclonic system over the WNP, while the anti-cyclonic system over the...
Indian Ocean weakened rapidly (Figure 5c). The background flow north of the equatorial changed from southwesterlies to northeasterlies. On the other hand, at the south of the equatorial region the background flow changed from southeasterlies to northwesterlies. This caused drastic changes to the SST over the region. The negative feedback mechanisms on the evaporative cooling processes, favored the significant increment of the SST over the region. The weakening of the anti-cyclonic system over the southern Indian Ocean and the strengthening of the anti-cyclonic system over the WNP shifted the dryer areas northeastward [4]. However, Peninsular Malaysia remained under dry conditions due to the easterlies/southeasterlies, which are part of the anti-cyclonic system over the WNP, that brought away the moisture flux from Peninsular Malaysia and the surrounding areas towards the southern Indian Ocean. The warmer (cooler) SST over the Indian Ocean (WNP) led to surface convergence (divergence). Therefore, the significant easterlies winds that prevailed from the WNP to the Indian Ocean brought significant moisture flux to the southern part of the Maritime Continent. The anti-cyclonic systems over the WNP and Indian Ocean are also part of the easterly wind. This is consistent with previous studies (i.e., [4,7,8,66]). The wetter than normal conditions over Sumatra, Java Island, and southern Borneo are due to the convergence and rising motion associated with the anti-cyclonic circulations over WNP and the southern Indian Ocean, resulting from symmetric Rossby waves [4,8,66,70]. The westerlies from the Bay of Bengal also transported the moisture flux from the western Indochina region to the WNP and fed back to the anti-cyclonic system (Figures 1c, 5c and 6c). The wetter conditions over Vietnam were caused by the SCS that was brought by southwesterlies, which are part from the anti-cyclonic system over the WNP. The interaction between the SST and anti-cyclonic system over the WNP have strengthened the dipole feature and also the anti-cyclonic circulation over that area, with a cooler pool on the east of the anti-cyclonic center and a warmer pool on its west. A significant downward air motion over the eastern Maritime Continent is also consistent with the dry conditions over the area (Figures 1c and 7c).

Generally, the circulation of the low-level wind anomalies during the pure El Niño events is more likely during the co-occurrence of both events, but relatively weaker. As mentioned earlier, the changes in the monsoonal background flow during the DJF season cause significant changes in the SST over SEA. The reverse wind directions between the monsoonal background flow and the low-level wind anomalies weaken the anomalous wind and cause negative feedback, which increases the SST in the Indian Ocean and the SCS. The northeastward evolution of the dry areas is also depicted in this event but is not significant. Over the Philippines, the dipole is also weaker, as is the anti-cyclonic system (Figure 3g). In accordance with the low-level wind anomalies, the weakening of the anti-cyclonic system over the Indian Ocean reduced the moisture divergence processes over the Maritime Continent. These two anti-cyclonic systems merged and became easterly winds at the southern part of the Maritime Continent, which brought moisture flux to that area from the southern Indian Ocean, west of Australia. The easterly wind from the WNP is not visible, thus causing the weakening of the cooler northern arm of the boomerang-shaped SST. Besides this, the western Pacific Ocean is a convergence pool itself. On the other hand, the dry conditions over the northeastern part of the Maritime Continent are driven away by the high-pressure anti-cyclonic system over the WNP. Besides this, the moisture flux from the Indochina region is transported to the WNP (Figures 1g, 5g and 6g). The 500 mb vertical velocity anomalies also show the descending air over the northeastern part of the Maritime Continent and the ascending air over its western part, which is consistent with the anomalous rainfall pattern during the events (Figure 7g).

On the other hand, during the pure IOD events the low-level wind circulation depicts a totally different pattern from that of the other two events (Figure 5k). During the DJF season, the background wind directions change as the monsoon season changes. The direction of the wind anomalies also changed from easterlies to westerlies over the equatorial Indian Ocean, weakening the thermohaline elevation (east) and suppression (west) process off Sumatra, which led to the decaying/termination of the IOD events. The anti-cyclonic system over the Bay of Bengal has disappeared and a cyclonic system has formed above the Bay of Bengal that may cause the dryer conditions over the northern part of
Indochina. A weak anti-cyclonic system is also observed over the WNP. The strong easterlies are part of the cyclonic system over the WNP, bringing an abundance of moisture towards the Maritime Continent and causing wetter than normal conditions (Figures 1k, 5k and 6k). Figure 7k also shows the upward air motions over the Maritime Continent, which explains the wetter than normal rainfall patterns over most of the Maritime Continent area. On the other hand, the decreasing air over eastern Indochina is also consistent with the negative rainfall anomaly patterns over the area (Figures 1k and 7k).

During the MAM season in the following year, the El Niño events are in the decaying phase and the IOD events are in their initial phase. Generally, the low-level wind circulation weakens from the previous season. The anti-cyclonic system over the WNP can still be observed but it is no longer due to the remote forcing from the WNP, since the El Niño signal has weakened during this season [66] (Figure 5d). However, in the decaying phase of the pure El Niño events, low-level wind circulation also weakens from the previous season. Both events that were related to El Niño signals were more likely to depict the same wind circulations and impacts on the anomalous rainfall distributions over the region (Figure 1d,h and Figure 5d,h). The negative rainfall continues to evolve further northeastward as the anti-cyclonic conditions over the Indian Ocean weaken and the WNP anti-cyclonic conditions dominate and slightly shift northward. Regions such as southern Sumatra, southern Borneo, and Java Island, which received more rainfall than normal, are associated with the convergence center over the southern Indian Ocean and the SCS due to the warmer SST (Figure 1d,h and Figure 6d,h). In this season, Peninsular Malaysia continued to experience drier than normal conditions (Figure 1d,h and Figure 6d,h). The 500 mb vertical velocity anomaly patterns during the co-occurrence of both events and the pure El Niño were consistent with the anomalous rainfall patterns over SEA (Figure 1d,h and Figure 7d,h). However, the downward air motions of SEA for both events were not significant.

On the other hand, during the early phase of the IOD event in the MAM season, the easterly anomaly winds from the western Pacific began to dominate the Maritime Continent and transported an abundance of moisture flux over the region (Figures 1l, 5l and 6l). The warmer SST surrounding SEA also leads to surface convergence, increases lower atmospheric water vapor, and enhances convection over the region. The reverse directions between the monsoonal background flow and the wind circulation anomalies in this season prevented the formation of a dipole related to an IOD event over the Indian Ocean. The Maritime Continent is dominated by ascending air, which is consistent with the positive precipitation anomaly pattern (Figures 1l and 7l).

3.3. The Walker Circulation

The variations in the Indian Ocean can be attributed to the variations in the Pacific Ocean through the mechanism of the Walker circulation [45]. The SST from one basin may affect the other basins through Walker circulation, which causes changes in the surface fluxes. This is because of the close relationship between the variations in the SST, heating, and atmospheric circulation anomalies. The connections between these two major oceans through the Walker circulation is also known as an “atmospheric bridge”. The remote forcing from both oceans, either individually or combined, would have a distinctive effect on SEA and Malaysia in particular. Figure 8 shows the composite average vertical velocity of 5° S to 5° N of the events listed in Table 1. Generally, the figures show that, during the co-occurrence of the El Niño and IOD events, the atmospheric bridge through the Walker circulation that connects the two oceans can be observed. The upward air motions occur over the eastern Pacific Ocean and Indian Ocean, while the downward air motions occur over the Maritime Continent and oceans nearby (the western Pacific and the eastern Indian Ocean) (Figure 8, left panel). The downward motion is consistent with the 500 mb vertical velocity features (Figure 7, left panel). This large-scale downward motion suppresses the convection in the Maritime Continent that provides dryer conditions over that region. The northeastward motion of the dryer conditions associated with the El Niño from the JJA to MAM season is also represented in the downward motions of the walker circulation (Figures 7 and 8; left panel). During the pure El Niño events in which the signal from the IOD events are separated, the upward air motions over the Indian Ocean weaken or are nearly normal.
The sinking motion pattern over the Maritime Continent during this event is similar with the combined events but weaker in magnitude, especially over the southwestern part of the Maritime Continent during JJA and SON, which is related to the IOD event (Figures 7 and 8; center panel). This reflects the dryer condition due to the suppressed convection over the region. (Figure 1; center panel). The northeastward evolution is also represented by the walker circulation and the 500 mb vertical velocity. Conversely, during the pure IOD events, the upward air motions over the eastern Pacific Ocean instead weaken or are near normal (Figure 8, right panel). However, during the DJF and MAM season, the upward air motions over the western Indian Ocean and the downward air motions over the eastern Indian Ocean and the Maritime Continent that relate to IOD events are not visible due to the termination of the IOD events (Figure 8k,l). During the JJA and SON seasons, the downward motion over the southern part of the Maritime Continent suppresses convection over that area, which leads to dryer conditions. On the other hand, during the following seasons upward motions were observed over the Maritime Continent, which enhances convection and causes wetter than normal conditions.

Figure 8. The composite of vertical velocity averaged from −5° S to −5° N for the events listed in Table 1. The hatched area indicates significance at 95% level. The y-axis is pressure level in hPa. (a–d) Co-occurrence of conventional El Niño and positive IOD, (e–h) pure conventional El Niño, and (i–l) pure positive IOD for the seasons of JJA, SON, DJF, and MAM. Unit is Pa s\(^{-1}\).

### 4. Summary

This study investigates the individual and combined effect of the pure El Niño and IOD events using composite and/or partial correlation analysis on the rainfall anomaly pattern over SEA. The results show that the impacts of the co-occurrence of the El Niño and IOD events are more significant compared to those of the individual effects of these events, especially over the southern part of the SEA during the JJA and SON seasons. In general, the negative impacts of the pure El Niño events over SEA are
weaker, as are the pure IOD events. The individual impacts of the pure El Niño and IOD events are similar. Both events caused negative impacts over the southern part of SEA during JJA and propagated northeastward/eastward during SON. Thus, there were significant negative impacts over that region when both individual events co-occurred.

In the DJF and MAM seasons, the El Niño-related rainfall anomaly patterns dominated SEA even during the co-occurrence of both events due to the termination of the IOD events during these seasons. However, the IOD termination intensified the strength of the features of the anomalies during the co-occurrence of these events. The negative effects associated with the pure El Niño dominated the north of the equator, due to the northeastward shifts through the year. However, Peninsular Malaysia remained dry throughout the year, especially during the co-existence of both events. In these seasons, the termination of the IOD events caused wetter than normal conditions over the Maritime Continent. During the MAM season, the negative effects associated with El Niño continued to move further towards the east coast.

The difference in the impacts of these phenomena on the anomalous rainfall patterns are related to the SST anomaly differences, differences in the anomalous regional atmospheric circulations, and differences in the anomalous Walker circulations over the Indian Ocean and the tropical Pacific Ocean. The pure IOD events are phase-locked to the JJA and SON seasons, where the SST dipole anomalies over the Indian Ocean formed with the horizontal wind. The strengthening and weakening of the boomerang-shaped SST over the western Pacific, dipole formation over the Indian Ocean, and heating/cooling processes over the Java Sea and the SCS influenced the rainfall patterns over the region. The combination of the low-level wind circulation anomalies associated with the El Niño and the IOD caused significant impacts on the SEA rainfall patterns. Therefore, during the JJA and SON seasons, the IOD events had maximum impacts on the SEA rainfall anomalies, especially during the co-occurrence of the El Niño and IOD events. The separation of the signals from each other leads to weaker intensity compared to those of combined events. The rainfall anomaly patterns over SEA are also consistent with the pattern of upward and downward air motions associated with the Walker circulation branch originating from the Pacific Ocean and (or) the Indian Ocean. The downward motion over the Maritime Continent suppresses the convection and leads to dryer conditions over that region.

The same mechanism applies to the DJF and MAM seasons. However, the changes in the monsoonal background flow in these seasons resulted in the negative feedback of the evaporative cooling, which led to the termination of the IOD event and provided warmer SST over the Indian Ocean during the events associated with El Niño (the pure El Niño and the co-occurrence of both events). On the other hand, cooler SST anomalies were observed over the Indian Ocean during the pure IOD events. The rainfall anomalies over SEA during the DJF and MAM seasons are also consistent with the ascending and descending air associated with the Walker circulation branch in the region, which was only observed over the Pacific Ocean and not over the Indian Ocean due to the termination of the IOD events.

The variations over the Indian Ocean can be attributed to variations over the Pacific Ocean through Walker circulation. Besides, SST from one basin may affect other basins through Walker circulation, causing a change in the surface flux. This is because of the close relationship between the variations in SST, heating, and atmospheric circulation anomalies. Remote forcing from both major oceans, either individually or combined, would have a significant effect on SEA. During the co-occurrence of both events in the JJA and MAM seasons, through Walker circulation the atmospheric bridge that connects the two oceans can be seen clearly. The upward air motions occurred over the eastern Pacific Ocean and the Indian Ocean, while the downward air motions were observed over the Maritime Continent and the oceans nearby (the western Pacific and eastern Indian Ocean). During the pure El Niño events, the ascending air over the Indian Ocean weakened or was almost normal. Conversely, during the pure IOD events, the ascending air over the eastern Pacific Ocean was not visible. Similarly, during the DJF and MAM seasons, the upward air motions over the western Indian Ocean and the downward
air motions over the eastern Indian Ocean and the Maritime Continent associated with the IOD were not visible in any of the types of events, including the pure IOD event itself, due to the termination of that event.

Overall, the present study has improved our understanding of how the individual and combined events of El Niño and IOD affect the SEA region according to season. Future study could also include the effect of the Madden–Julian Oscillation (MJO). The size of sample needs to be considered carefully for more robust results in the future.

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References

1. Rasmusson, E.M.; Carpenter, T.H. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. Mon. Weather Rev. 1982, 110, 354–384. [CrossRef]
2. Nicholls, N.; Kariko, A. East Australia rainfall events: Interannual variations, trends, and relationships with the Southern Oscillation. J. Clim. 1993, 6, 1141–1152. [CrossRef]
3. Hendon, H.H. Indonesian rainfall variability: Impacts of ENSO and local air–sea interaction. J. Clim. 2003, 16, 1775–1790. [CrossRef]
4. Juneng, L.; Tangang, F.T. Evolution of ENSO-related rainfall anomalies in Southeast Asia region and its relationship with atmosphere–ocean variations in Indo-Pacific sector. Clim. Dyn. 2005, 25, 337–350. [CrossRef]
5. Tangang, F.; Latif, M.; Juneng, L. Climate Change: Is Southeast Asia up to the Challenge? The Roles of Climate Variability and Climate Change on Smoke Haze Occurrences in Southeast Asia Region. 2010. LSE IDEAS. Available online: eprints.lse.ac.uk/4357/1/Climate%20variability%20change%20in%20Southeast%20Asia%20region.pdf (accessed on 27 April 2013).
6. Salimun, E.; Tangang, F.; Juneng, L.; Behera, S.K.; Yu, W. Differential impacts of conventional El Niño versus El Niño Modoki on Malaysian rainfall anomaly during winter monsoon. Int. J. Climatol. 2014, 34, 2763–2774. [CrossRef]
7. Tangang, F.; Farzanmanesh, R.; Mirzaei, A.; Supari; Salimun, E.; Jamaluddin, A.F.; Juneng, L. Characteristics of precipitation extremes in Malaysia associated with El Niño and La Niña events. Int. J. Climatol. 2017, 37, 696–716. [CrossRef]
8. Tangang, F.S.; Salimun, E.; Aldrian, E.; Sapaheluwakan, A.; Juneng, L. ENSO modulation of seasonal rainfall and extremes in Indonesia. Clim. Dyn. 2018, 51, 2559–2580.
9. Behera, S.K.; Krishnan, R.; Yamagata, T. Unusual ocean–atmosphere conditions in the tropical Indian Ocean during 1994. Geophys. Res. Lett. 1999, 26, 3001–3004. [CrossRef]
10. Saji, N.H.; Goswami, B.N.; Vinayachandran, P.N.; Yamagata, T. A dipole mode in the tropical Indian Ocean. Nature 1999, 401, 360–363. [CrossRef]
11. Webster, P.J.; Moore, A.M.; Loschnigg, J.P.; Leben, R.R. Coupled ocean–atmosphere dynamics in the Indian Ocean during 1997–98. Nature 1999, 401, 356–360. [CrossRef]
12. Yamagata, T.; Behera, S.K.; Rao, S.A.; Guan, Z.; Ashok, K.; Saji, H.N. Comments on “Dipoles, Temperature Gradient, and Tropical Climate Anomalies”. Bull. Am. Meteorol. Soc. 2003, 84, 1418–1422. [CrossRef]
13. Saji, N.H.; Yamagata, T. Possible impacts of Indian Ocean Dipole Mode events on global climate. Clim. Res. 2003, 25, 151–169. [CrossRef]
14. Hamada, J.I.; Mori, S.; Kubota, H.; Yamanaka, M.D.; Haryoko, U.; Lestari, S.; Sulistyowati, R.; Syamsudin, F. Interannual rainfall variability over northwestern Jawa and its relation to the Indian Ocean Dipole and El Niño-Southern Oscillation events. SOLA 2012, 8, 69–72. [CrossRef]
15. Hidayat, R.; Ando, K.; Masumoto, Y.; Luo, J.J. Interannual variability of rainfall over Indonesia: Impacts of ENSO and IOD and their predictability. *IOP Conf. Ser. Earth Environ. Sci.* 2016, 31, 012034. [CrossRef]

16. Ashok, K.; Guan, Z.; Saji, N.H.; Yamagata, T. Individual and combined influences of ENSO and the Indian Ocean dipole on the Indian summer monsoon. *J. Clim.* 2004, 17, 3141–3155. [CrossRef]

17. Ashok, K.; Nakamura, H.; Yamagata, T. Impacts of ENSO and Indian Ocean dipole events on the Southern Hemisphere storm-track activity during austral winter. *J. Clim.* 2007, 20, 3147–3163. [CrossRef]

18. Ashok, K.; Saji, N.H. On the impacts of ENSO and Indian Ocean dipole events on sub-regional Indian summer monsoon rainfall. *Nat. Hazards* 2007, 42, 273–285. [CrossRef]

19. Cha, E.J. El Niño-Southern oscillation, Indian Ocean dipole mode, a relationship between the two phenomena, and their impact on the climate over the Korean peninsula. *JKES* 2007, 28, 35–44. [CrossRef]

20. Pillai, P.A.; Mohankumar, K. Individual and combined influence of El Niño–Southern oscillation and Indian Ocean dipole on the tropospheric biennial oscillation. *Q. J. R. Meteorol. Soc.* 2010, 136, 297–304. [CrossRef]

21. Manatsa, D.; Matarira, C.H.; Mukwada, G. Relative impacts of ENSO and Indian Ocean dipole/zonal mode on east SADC rainfall. *Int. J. Climatol.* 2011, 31, 558–577. [CrossRef]

22. Sankar, S.; Kumar, M.R.; Reason, C. On the relative roles of El Niño and Indian Ocean Dipole events on the Monsoon Onset over Kerala. *Theor. Appl. Climatol.* 2011, 103, 359–374. [CrossRef]

23. Cai, W.; Van Rensch, P.; Cowan, T.; Hendon, H.H. An asymmetry in the IOD and ENSO teleconnection pathway and its impact on Australian climate. *J. Clim.* 2012, 25, 6318–6329. [CrossRef]

24. As-syakur, A.R.; Adnyana, I.W.S.; Mahendra, M.S.; Arthana, I.W.; Merit, I.N.; Kasa, I.W.; Ekayanti, N.W.; Nuarsa, I.W.; Sunarta, I.N. Observation of spatial patterns on the rainfall response to ENSO and IOD over Indonesia using TRMM Multisatellite Precipitation Analysis (TMPA). *Int. J. Climatol.* 2014, 34, 3825–3839. [CrossRef]

25. Gaughan, A.E.; Staub, C.G.; Hoell, A.; Weaver, A.; Waylen, P.R. Inter-and Intra-annual precipitation variability and associated relationships to ENSO and the IOD in southern Africa. *Int. J. Clim.* 2016, 36, 1643–1656. [CrossRef]

26. Lestari, R.K.; Koh, T.Y. Statistical evidence for asymmetry in ENSO–IOD interactions. *Atmos. Ocean* 2016, 54, 498–504. [CrossRef]

27. Wang, H.; Murtugudde, R.; Kumar, A. Evolution of Indian Ocean dipole and its forcing mechanisms in the absence of ENSO. *Clim. Dyn.* 2016, 47, 2481–2500. [CrossRef]

28. Agilan, V.; Umamahesh, N.V. Changes in ENSO and IOD effects on the extreme rainfall of Hyderabad city, India. In *Climate Change Impacts*; Singh, V., Yadav, S., Yadava, R.N., Eds.; Springer: Singapore, 2018; pp. 91–100.

29. Chanda, A.; Das, S.; Mukhopadhyay, A.; Ghosh, A.; Akhand, A.; Ghosh, P.; Ghosh, T.; Mitra, D.; Hazra, S. Sea surface temperature and rainfall anomaly over the Bay of Bengal during the El Niño-Southern Oscillation and the extreme Indian Ocean Dipole events between 2002 and 2016. *Remote Sens. Appl. Soc. Environ.* 2018, 12, 10–22. [CrossRef]

30. Allan, R.J.; Chambers, D.; Drosdowsky, W.; Hendon, H.; Latif, M.; Nicholls, N.; Smith, I.; Stone, R.; Tourre, Y. Is there an Indian Ocean dipole and is it independent of the El Niño-Southern Oscillation? *Clivar Exch.* 2001, 6, 18–22.

31. Baquero-Bernal, A.; Latif, M.; Legutke, S. On dipole-like variability of sea surface temperature in the tropical Indian Ocean. *J. Clim.* 2002, 15, 1358–1368. [CrossRef]

32. Yamagata, T.; Behera, S.K.; Luo, J.J.; Masson, S.; Jury, M.R.; Rao, S.A. Coupled ocean-atmosphere variability in the tropical Indian Ocean. In *Earth’s Climate: The Ocean-Atmosphere Interaction*; Wang, C., Xie, S.P., Carton, J.A., Eds.; American Geophysical Union: Washington, DC, USA, 2004; Volume 147, pp. 189–211.

33. Vinayachandran, P.N.; Francis, P.A.; Rao, S.A. *Indian Ocean Dipole: Processes and Impacts*; Current Trends in Science: Platinum Jubilee Special; Indian Academy of Sciences: Bangalore, India, 2009; pp. 569–589.

34. Ashok, K.; Guan, Z.; Yamagata, T. A look at the relationship between the ENSO and the Indian Ocean Dipole. *J. Meteorol. Soc. Jpn.* 2003, 81, 41–56. [CrossRef]

35. Shinoda, T.; Alexander, M.A.; Hendon, H.H. Remote response of the Indian Ocean to interannual SST variations in the tropical Pacific. *J. Clim.* 2004, 17, 362–372. [CrossRef]

36. Behera, S.K.; Luo, J.J.; Masson, S.; Yamagata, T.; Delecluse, P.; Gualdi, S.; Navarra, A. Impact of the Indian Ocean Dipole on the East African short rains: A CGCM study. *Clivar Exch.* 2003, 27, 43–45.
37. Behera, S.K.; Luo, J.J.; Masson, S.; Rao, S.A.; Sakumo, H.; Yamagata, T. A CGCM study on the interaction between IOD and ENSO. *J. Clim.* 2006, 19, 1688–1705. [CrossRef]
38. Cai, W.; Hendon, H.H.; Meyers, G. Indian Ocean dipole-like variability in the CSIRO Mark 3 coupled climate model. *J. Clim.* 2005, 18, 1449–1468. [CrossRef]
39. Cai, W.; Sullivan, A.; Cowan, T. Interactions of ENSO, the IOD, and the SAM in CMIP3 models. *J. Clim.* 2011, 24, 1688–1704. [CrossRef]
40. Jourdain, N.C.; Gupta, A.S.; Taschetto, A.S.; Ummenhofer, C.C.; Moise, A.F.; Ashok, K. The Indo-Australian monsoon and its relationship to ENSO and IOD in reanalysis data and the CMIP3/CMIP5 simulations. *Clim. Dyn.* 2013, 41, 3073–3102. [CrossRef]
41. Jourdain, N.C.; Lengaigne, M.; Vialard, J.; Izumo, T.; Gupta, A.S. Further insights on the influence of the Indian Ocean dipole on the following year’s ENSO from observations and CMIP5 models. *J. Clim.* 2016, 29, 637–658. [CrossRef]
42. Krishnaswamy, J.; Vaidyanathan, S.; Rajagopalan, B.; Bonell, M.; Sankaran, M.; Bhalla, R.S.; Badiger, S. Non-stationary and non-linear influence of ENSO and Indian Ocean Dipole on the variability of Indian monsoon rainfall and extreme rain events. *Clim. Dyn.* 2015, 45, 175–184. [CrossRef]
43. Lau, N.-C.; Nath, M.J. Coupled GCM simulation of atmosphere–ocean variability associated with zonally asymmetric SST changes in the tropical Indian Ocean. *J. Clim.* 2004, 17, 245–265. [CrossRef]
44. Wang, H.; Kumar, A.; Murtugudde, R.; Narapasetty, B.; Seip, K.L. Covariations between the Indian Ocean and ENSO: A modeling study. *Clim. Dyn.* 2019, 53, 5743–5761. [CrossRef]
45. Wu, R.; Kirtman, B.P. Understanding the impacts of the Indian Ocean on ENSO variability in a coupled GCM. *J. Clim.* 2004, 17, 4019–4031. [CrossRef]
46. Lizuka, S.; Matsuura, T.; Yamagata, T. The Indian Ocean SST dipole simulated in a coupled general circulation model. *Geophys. Res. Lett.* 2000, 27, 3369–3372. [CrossRef]
47. D’Arrigo, R.; Wilson, R. El Niño and Indian Ocean influences on Indonesian drought: Implications for forecasting rainfall and crop productivity. *Int. J. Climatol.* 2008, 28, 611–616. [CrossRef]
48. Xu, K.; Zhu, C.; Wang, W. The cooperative impacts of the El Niño–Southern Oscillation and the Indian Ocean Dipole on the interannual variability of autumn rainfall in China. *Int. J. Climatol.* 2016, 36, 1987–1999. [CrossRef]
49. Rao, S.A.; Masson, S.; Luo, J.J.; Behera, S.K.; Yamagata, T. Termination of Indian Ocean dipole events in a coupled general circulation model. *J. Clim.* 2007, 20, 3018–3035. [CrossRef]
50. Behera, S.K.; Luo, J.J.; Masson, S.; Delecluse, P.; Gualdi, S.; Navarra, A.; Yamagata, T. Paramount impact of the Indian Ocean dipole on the East African short rains: A CGCM study. *J. Clim.* 2005, 18, 4514–4530. [CrossRef]
51. Behera, S.K.; Luo, J.J.; Yamagata, T. The unusual IOD event of 2007. *Geophys. Res. Lett.* 2008, 35. [CrossRef]
52. Ummenhofer, C.C.; Gupta, A.S.; England, M.H.; Reason, C.J.C. Contributions of Indian Ocean sea surface temperatures to enhanced East African rainfall. *J. Clim.* 2009, 22, 993–1013. [CrossRef]
53. Lestari, D.O.; Sutriyono, E.; Kadir, S.; Iskandar, I. Severe drought event in Indonesia following 2015/16 El Niño/positive Indian dipole events. *J. Phys. Conf. Ser.* 2018, 1011, 012040. [CrossRef]
54. Kalnay, E.; Kanamitsu, M.; Kistler, R.; Collins, W.; Deaven, D.; Gandin, L.; Iredell, M.; Saha, S.; White, G.; Woollen, J.; et al. The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteorol. Soc.* 1996, 77, 437–472. [CrossRef]
55. Rayner, N.A.; Parker, D.E.; Horton, E.B.; Folland, C.K.; Alexander, L.V.; Rowell, D.P.; Kent, E.C.; Kaplan, A. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res. Atmos.* 2003, 108. [CrossRef]
56. Becker, A.; Finger, P.; Meyer-Christoffe, A.; Rudolf, B.; Schamm, K.; Schneider, U.; Ziese, M. A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901–present. *Earth Syst. Sci. Data* 2013, 5, 921–998. [CrossRef]
57. Reverdin, G.; Cadet, D.L.; Gutzler, D. Interannual displacements of convection and surface circulation over the equatorial Indian Ocean. *Q. J. R. Meteorol. Soc.* 1986, 112, 43–67. [CrossRef]
58. Hastenrath, S.; Nicklis, A.; Greischar, L. Atmospheric–hydrospheric mechanisms of climate anomalies in the western equatorial Indian Ocean. *J. Geophys. Res. Oceans* 1993, 98, 20219–20235. [CrossRef]
59. Murtugudde, R.; McCreary, J.P.; Busalacchi, A.J. Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997–1998. *J. Geophys. Res. Oceans.* 2000, 105, 3295–3306. [CrossRef]

60. Horii, T.; Hanawa, K. A relationship between timing of El Niño onset and subsequent evolution. *Geophys. Res. Lett.* 2004, 31. [CrossRef]

61. Xu, J.; Chan, J.C.L. The role of the Asian-Australian monsoon system in the onset time of El Niño events. *J. Clim.* 2001, 14, 418–433. [CrossRef]

62. Mahmud, M. Peristiwa El Niño dan Pengaruh IOD Terhadap Hujan di Malaysia (El Niño Events and the Influence of IOD on Rainfall in Malaysia). *J. Soc. Sci. Humanit.* 2018, 13, 166–177.

63. Ratna, S.B.; Ratnam, J.V.; Behera, S.K.; Tangang, F.T.; Yamagata, T. Validation of the WRF regional climate model over the subregions of Southeast Asia: Climatology and interannual variability. *Clim. Res.* 2017, 71, 263–280. [CrossRef]

64. Clarke, A.J.; Liu, X. Interannual sea level in the northern and eastern Indian Ocean. *J. Phys. Oceanogr.* 1994, 24, 1224–1235. [CrossRef]

65. Meyers, G. Variations of Indonesian through flow and the El Niño-Southern Oscillation. *J. Geophys. Res. Oceans* 1996, 101, 12255–12263. [CrossRef]

66. Wang, B.; Wu, R.; Li, T. Atmosphere-warm ocean interaction and its impacts on Asian-Australian monsoon variation. *J. Clim.* 2003, 16, 1195–1211. [CrossRef]

67. Yamagata, T.; Behera, S.K.; Rao, S.A.; Guan, Z.; Ashok, K.; Saji, H.N. The Indian Ocean Dipole: A physical entity. *Clim. Exch.* 2002, 24, 2.

68. Lau, N.-C.; Nath, M.J. Atmosphere-ocean variations in the Indo-Pacific sector during ENSO episodes. *J. Clim.* 2003, 16, 3–20. [CrossRef]

69. Bjerknes, J. Atmospheric teleconnections from the equatorial Pacific. *Mon. Weather Rev.* 1969, 97, 163–172. [CrossRef]

70. Gill, A.E. Some simple solutions for heat-induced tropical circulation. *Q. J. R. Meteorol. Soc.* 1980, 106, 447–462. [CrossRef]