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Variability of Southwest Monsoon Onset and Withdrawal Dates in East Coast Peninsular Malaysia

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ABSTRACT

The accurate prediction of the onset and withdrawal of the southwest monsoon (SWM) is crucial to the economic and social well-being of the local community whose livelihoods depend strongly on monsoon rains. To date however, there has been a paucity of research into the prediction of SWM timing in east coast Peninsular Malaysia (ECPM) as compared to other monsoon regions. Thus, this study attempts to identify the variability of SWM dates in ECPM and analyze the influence of ENSO on the timing of SWM. Composites of daily 850 hPa zonal winds and outgoing long-wave radiation (OLR) during 2000-2020 were analyzed. The SWM onset is identified by the sudden acceleration of southerly winds in mid-May, while the retreating SWM wind is recognized by the steady decrease of westerly winds through September until October. The average date of SWM onset and withdrawal over ECPM was found to be May 23rd and September 27th, respectively. ENSO has a greater influence on the SWM onset than the SWM withdrawal. The study adds to our understanding of the inter-annual variability of SWM start and retreat dates, laying the groundwork for future research into the impact of climate change on the monsoon timing variability in the study area.

1. INTRODUCTION

Being situated within the Maritime Continent, the Malaysian region experiences profound weather patterns due to influence of the Southeast Asian summer monsoon (SEASM) and winter monsoon. The winter northeast monsoon (NEM) occurs from November to February, while the summer southwest monsoon (SWM) typically starts in late May or early June and lasts until September. Unlike the NEM, the SWM is associated with a relatively dry phase during the active monsoon months. Similar to the South Asian summer monsoon (SASM) and East Asian summer monsoon (EASM), the onset of the SWM over the Southeast Asia region marks a crucial transition from the dry period to the summer rainy season, while its withdrawal signifies the conclusion of the summer rainy season [1-3].

This monsoonal transition plays a pivotal role in replenishing the region's water resources and facilitating agricultural activities [4]. Moreover, the onset of the SWM in this region is intricately linked to the broader regional atmospheric circulation patterns of the Asian continent. Studies by various researchers (e.g., [5-9]) emphasize that the timing and intensity of the SWM's onset over Southeast Asia play a crucial role in shaping the strength, duration, and evolution of the EASM.

The timing of the monsoon has significant socioeconomic consequences, especially in regions that rely heavily on rain-fed agriculture [10]. Delayed monsoon onset can lead to yield loss, affecting local and global food security. The withdrawal of the monsoon is also critical to communities as it marks the end of the rainy season [11]. In Malaysia, where the SWM plays

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a crucial role in shaping the weather patterns, early and precise prediction of its onset is essential for effective resource management. For instance, intense El Niño events that cause forest fires in neighbouring countries have resulted in severe cross-border haze that impacted Malaysia [12]. This haze has various negative effects, including threats to public health and water supplies, as well as disruptions to transportation activities. To date however, there is minimal observational data on the onset and withdrawal dates of the SWM in east coast Peninsular Malaysia (ECPM) as compared to other continents such as Africa and India, and prior studies have primarily focused on monsoon onset [1, 13-15], with little attention paid to withdrawal variability [16].

Monsoon onset and withdrawal dates are complex phenomena that depend on various variables and factors. One common variable used to identify monsoon onset is low-level wind, particularly at 850 hPa, which is less noisy and has less variation than rainfall distribution. In the South China Sea (SCS), the shift in low-level wind direction from easterly to westerly has been used extensively as a critical indicator of the onset of the summer monsoon season [1]. In addition, various criteria and parameters have also been used to determine monsoon timing variability, such as outgoing longwave radiation (OLR) and wind shear. For example, Chenoli et al. [13] modified the methods used by Diong et al. [4] and Wang et al. [1] to develop a monsoon onset index based on multiple criteria, including 850-200 hPa wind shear and OLR. Moreover, Zhou and Chan [17] analyzed 40-year reanalysis data that included daily and monthly mean values of zonal wind at 850 and 200 hPa and 25 years of OLR to develop a multiparameter index for monsoon onset. In general, a combination of various variables and parameters can provide a more accurate representation of monsoon onset and withdrawal dates, which are critical for agricultural planning, water resource management, and disaster preparedness.

Another commonly used variable to identify the monsoon timing is the climatology precipitation rate for a specified rainy season. For example, Asharaf et al. [18] has successfully used a strict threshold of surface moist static energy to define the onset of the Indian monsoon, while also exploring the role of soil moisture. However, in Malaysia, using precipitation as an indicator can be problematic due to increased diurnal convective activities during the maximum rainfall period. Instead, Malaysia's SWM is characterized by dry epochs with low daily rainfall (< 10 mm) and high OLR (> 220 W m^{-2}) values [4]. Nevertheless, rainfall can be standardized and normalized to demonstrate that it is substantially less during the summer monsoon, and this standardized and normalized rainfall can be used as an indicator of the monsoon's arrival [1]. However, despite this beneficial skill comparison, the commencement in a few years was underestimated due to sub-seasonal factors occurrence, such as intra-seasonal oscillation. As a result, it does not adequately capture the start of rainfall extremes. This index is believed to be subjective (at least to some extent) and vulnerable to large variations, making it impossible to predict monsoon circulation time.

In particular, the onset and withdrawal of the monsoon can be influenced by El Niño-Southern Oscillation (ENSO), with El Niño events delaying the onset date of the monsoon and La Niña events advancing it [11]. The withdrawal of the monsoon is also affected by ENSO, with El Niño delaying the withdrawal and La Niña advancing it. In general, the sea surface temperatures in the eastern and central Pacific Ocean become unusually warm during an El Niño event, leading to changes in atmospheric circulation patterns and this can affect the monsoon. Similarly, during La Niña event, the sea surface temperatures in the same region become unusually cool, which can also affect the monsoon. These factors contribute to the interannual variability of Asian monsoons and can make it difficult to predict the timing of monsoon circulation.

Although the timing of the southwest monsoon in the Asian region has been a focus of investigation in recent years, there is still a lack of studies in the Malaysian region. The only previous study was conducted by Chenoli et al. [13], who investigated the onset dates of the SWM over a 35-year period (1981-2015) based on OLR, daily rainfall and average wind vector data between 850 and 600 hPa. Chenoli et al. [13] found that the SWM onset date over the entire region of Malaysia was 19 May, with a standard deviation of 8 days. Additionally, they also observed that monsoon onset tends to be late during the El Niño years and earlier during the La Niña years. Considering the evolution of southwest monsoon, which covers the development of atmospheric processes throughout the entire season, the determination of the SWM withdrawal is as crucial as its onset, given its impact on various aspects of the environment, agriculture, and society. However, the evolution associated with the monsoon withdrawal, its timing and variability has not yet been investigated in this country. While there are similarities in the monsoon cycle in Malaysia region, local variations, especially in the timing of monsoon, may exist, due to the wide variety of synoptic and intra-seasonal fluctuations as well as its spatial variability [19-20]. Considering these factors, a unified onset across the entire region, as defined by a previous study (e.g., [13]), may be insufficient for establishing a clear timeline of SWM timing at a local scale and in other regions of Malaysia. Hence, in specific sub-regions such as the ECPM, the SWM may arrive either earlier or later by a span of days than the previously defined monsoon dates. This study aims to address these gaps by implementing an objective and consistent technique for determining the local onset and withdrawal dates in ECPM. Furthermore, the study analyzes the interannual variability of the onset and withdrawal dates and explores the potential influence of ENSO on these variations.

2. MATERIAL AND METHODS

2.1 Dataset

Peninsular Malaysia is situated near the Equator, with latitudes ranging from 1°0"N to 7°0"N and 100°0"E to 105°0"E. It is subjected to a climate with nearly uniform temperature and high humidity all year round due to its location in the tropical region and being surrounded by seas (South China Sea on the east and Malacca Straits on the west). Specifically, the area of interest is restricted to ECPM waters which has a shallow continental shelf basin with an average depth of 60m and is directly facing the SCS. Figure 1 shows the location of study area along with the two target domains (Bay of Bengal and Philippine waters), which were used to determine the monsoon onset and withdrawal in the study area.

This study used the 5th-generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA5) of OLR and wind vector at 850 hPa for 21 years (2000-2020), covering from May to October each year. ERA5 is an updated climate reanalysis dataset distributed by the Copernicus Climate Change Service (C3S) and processed and released by the ECMWF [21]. These daily data were obtained from the Climate Data Store website (https://cds.climate.copernicus.eu/) on regular latitude-longitude grids at 0.25° x 0.25° resolution. In addition, daily Oceanic Niño Index (ONI) data from January 2000 until December 2020 were also used to study the impact of ENSO on the variability of SWM onset and withdrawal dates. The ONI, commonly calculated as the running 3-month mean SST anomaly, serves as a key metric in characterizing and determining the occurrences of El Niño and La Niña events.

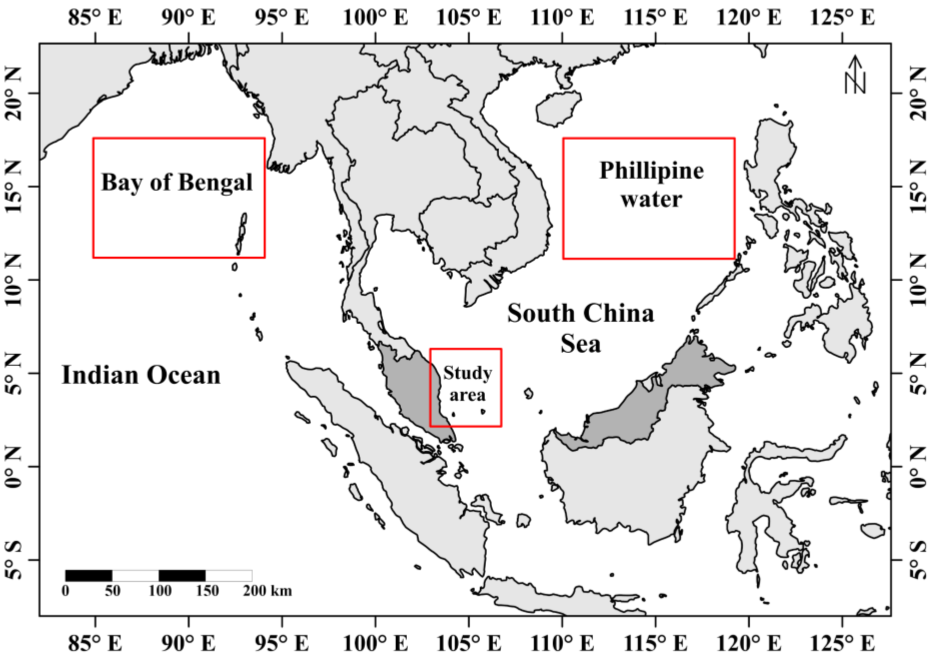

Fig. 1. The box encircled by red solid lines represents the study area and two reference domains (Bay of Bengal and Philippine waters) used to determine the monsoon onset and withdrawal.

In this study, we utilized ONI 3.4, which represents the average equatorial sea surface temperature (SST) anomalies in the Niño 3.4 region (5° N - 5° S, 120° W to 170° W). ONI data were taken from the NOAA Physical Sciences Laboratory (PSL) website (https://psl.noaa.gov/enso/data.html). To minimize the impact of high frequency variations and focus solely on interannual variability, the daily ONI was initially averaged on a monthly basis before being smoothed using a 12-month running average. A detailed summary of the data used is given in Table 1

Table 1. A summary of the data used in this study.

Dataset	Product Type	Year	Month
Daily u-component of wind at 850 hPa	ECMWF ERA5 reanalysis	2000-2020	April-October
Daily OLR	ECMWF ERA5 reanalysis	2000-2020	April-October
Daily ENSO	Oceanic Niño Index	2000-2020	April-October

2.2 Criteria to Identify Onset and Withdrawal Dates

It has long been recognized that the onset of SWM in the SCS region is marked by the sudden onset of deep convection and a reversal of surface winds from easterly to westerly (e.g., [22-25]). It has also been suggested that enhanced convection over the Bay of Bengal and Philippine waters in mid-May marks the onset of dry summer monsoon over the maritime continent [26-28]. The enhanced convection over these regions is usually coupled with the strengthening of 850 hPa westerly winds [13, 22]. Thus, in this study, the criteria that based on convection and wind at those two convection areas were employed to define both the onset and withdrawal dates of SWM. Following the method of Wang and Fan [22], the meridional shear index and OLR value averaged over the Bay of Bengal (10° N – 17.5° N, 85° E to 95° E) and Philippine (10° N – 17.5° N, 110° E to 120° E) waters were calculated using the daily ERA5 data from May to October for each individual year.

The meridional shear index was calculated by subtracting the area-averaged zonal wind vector at 850 hPa over ECPM waters from the area-averaged wind vector over Bay of Bengal and Philippine waters. The onset date is defined as the date when the meridional shear index is negative for at least five consecutive days while the withdrawal date is determined as the date when the shear index is positive for at least five consecutive days. The following formula was used to compute the meridian wind shear index (MSI_{850}):

$$MSI_{850} = \text{Average } U_{850[C]} - \text{Average } U_{850[A+B]} \tag{1}$$

where U_{850} is the zonal wind at 850 hPA over the study area ($U_{850[C]}$) and the two reference domains; Bay of Bengal and Philippine waters (($U_{850[A+B]}$).

The second criterion is to check whether the value of OLR in the study area is larger than 240 W m^{-2} because it is associated with less convection and low rainfall during SWM. OLR value greater than 240 W m^{-2} indicates the onset while the occurrence of OLR smaller than 240 W m^{-2} indicates monsoon withdrawal. This is in line with what Wu [29] has suggested that the highest convective activity in the tropics is reflected by an OLR of less than 240 W m^{-2}. Using the established criteria above, the frequency distribution of pentad averages is used to extract the onset and withdrawal dates in the study area over the past two decades. Table 2 summarizes the criteria for monsoon onset and withdrawal over the study area. For all the variables, climatological pentad means of daily zonal wind and OLR were constructed and analyzed in R software and Microsoft Excel.

Table 2. Criteria to determine the monsoon onset and withdrawal dates.

Variables	Onset/withdrawal	Criteria
Wind vector	Onset	Negative meridional shear index for at least five consecutive days.
	Withdrawal	Positive meridional shear index for at least five consecutive days.
OLR	Onset	Larger than 240 W m^{-2}.
	Withdrawal	Smaller than 240 W m^{-2}.

3. RESULTS AND DISCUSSIONS

3.1 The Evolution of Zonal Wind Fields and OLR

To gain a comprehensive understanding of changes in circulation before and during the SWM season, we analyzed the climatological pentad means (2000-2020) of easterly winds at 850 hPa and OLR. As shown in Figure 2, it can be seen that during the first pentad in May (01 - 05 May), the SCS was dominated by higher OLR (240 - 290 W m^{-2}) with shallow convection, and steady winds, indicating warm pre-monsoon dry season. Over the ECPM, the OLR exhibits a slightly lower value (~250 W m^{-2}) and very clam winds (< 0.5 m s^{-1}) compared to the SCS. Progressing to mid-May (11 - 15 May), OLR in the Indochina peninsula gradually decreases (220 – 230 W m^{-2}), with regions of elevated OLR retreating eastward to western Pacific Ocean and westward to the Indian subcontinent. During this period, the easterly winds in the SCS start to weaken, and they are gradually replaced by the monsoonal southwesterly. A reversed pattern is also evident over the ECPM region, marked by a slight intensification of convection (OLR < 230 W m^{-2}) and a persistent southwesterly wind (~ 2 m s^{-1}). After mid-May (16 - 20 May) minimum OLR (< 200 W m^{-2}) region begins its northward migration along the southern coast of Thailand, reaching the Indochina Peninsula by late May (26 - 30 May).

Furthermore, a sudden increase in convection over the SCS becomes apparent after mid-May, in conjunction with the strong southwesterly winds that extend diagonally from the Indian Ocean to the SCS. In the meantime, the evolution of horizontal flow field at 850 hPa during this period in the ECPM also indicates a significant increase in the speed of southwest flow (~3 m s^{-1}), accompanied by enhanced convection activities, as evidenced by OLR values below 210 Wm m^{-2}. Thus, mid-May marks a crucial turning point for the onset of SWM over ECPM as well as other regions in Indochina peninsula and the SCS. This result aligns with previous studies (e.g., [26-28]), which observed large-scale abrupt seasonal shifts in mid-May over the Bay of Bengal and Philippine waters. Commencing in early Jun (31 May - 09 June), the high OLR observed over the ECPM, as well as Pacific and Indian subcontinent gradually diminishes, signifying the progression of the summer monsoon across the region. It is important to highlight that the majority of the strong SWM flows appear to concentrate in the northwestern part of the Peninsular Malaysia and the SCS.

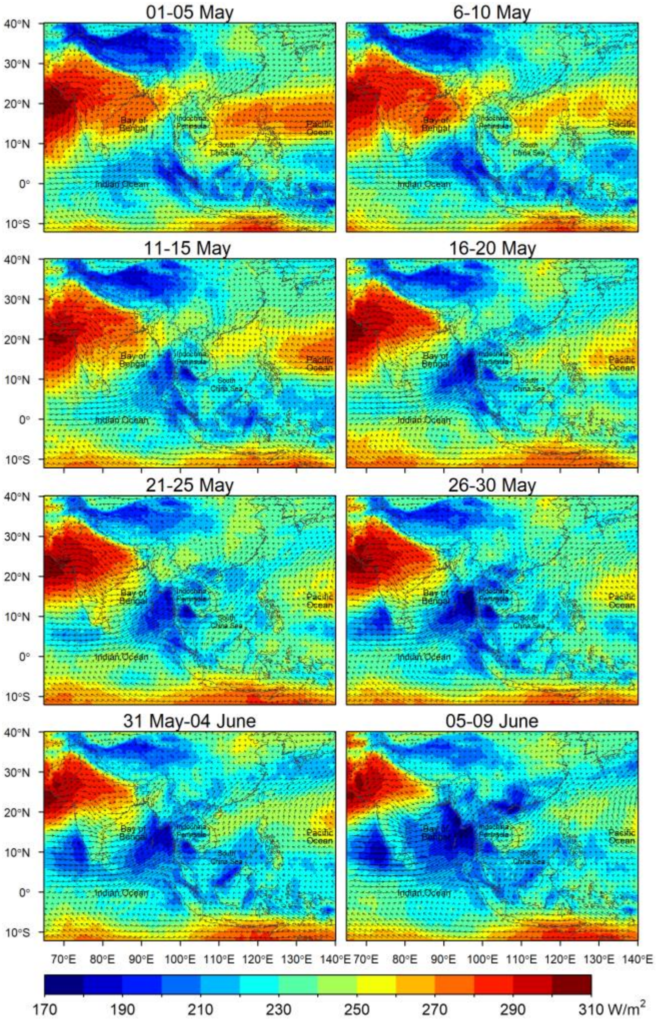

Fig. 2. Mean regional circulation and characteristics of the SWM onset from 2000 to 2020 in the study region.

Figure 3 illustrates the regional circulation and distribution of OLR towards the end of SWM. In early September (06 – 10 Sept), almost the whole region (0^o - 20^o N) is under the influence of the SWM, characterizing by persistent convective activities (OLR < 200 W m^{-2}) and strong westerly winds (between 4 and 8 m s^{-1}). Progressing to mid-Sept (16 - 20 Sept), there is a gradual change in the weather pattern, signifying the initiation of the SWM withdrawal phase. During this period, the OLR value shows a gradual increase (> 220 W m^{-2}) across the Indochina peninsula and the northern SCS, along with a transition from westerly to easterly winds in the northern SCS. Meanwhile, the monsoonal westerlies continue to prevail over Indochina peninsula. However, strong convection activities remain over the ECPM, with an area of low OLR (< 200 W m^{-2}) extending east-west from 75 ^{o}E to 130 ^{o}E along the equator. Due to the relatively stable surface temperature, low OLR variations in this region are strongly attributed to changes in cloudiness [30], and thus can be linked to variations in precipitation associated with the monsoonal circulation and the intertropical convergence zone (ITCZ). During late September (21 – 25 Sept), a notable shift in monsoon circulation is evident as the maximum OLR region emerges over the Indochina peninsula, southern SCS (ECPM) and eastern Indian Ocean, suggesting that late September is an important turning period of the withdrawal of SWM over the region. During this time, the monsoon troughs (areas of low OLR), split into two sections due to a weak subtropical ridge (areas of high OLR) subsequently leading to a weakening of the SWM winds. The minimum OLR in the ECPM is also observed to gradually increase, with values ranging between 220 and 240 W m^{-2}, while the southwesterly wind flow remains persistent as in the previous period. It can also be seen that the wind field over Indochina peninsula is almost easterlies after late September while the convection and monsoon westerlies seem to survive longer over the southern SCS and ECPM as late as mid-October (11 - 15 Oct).

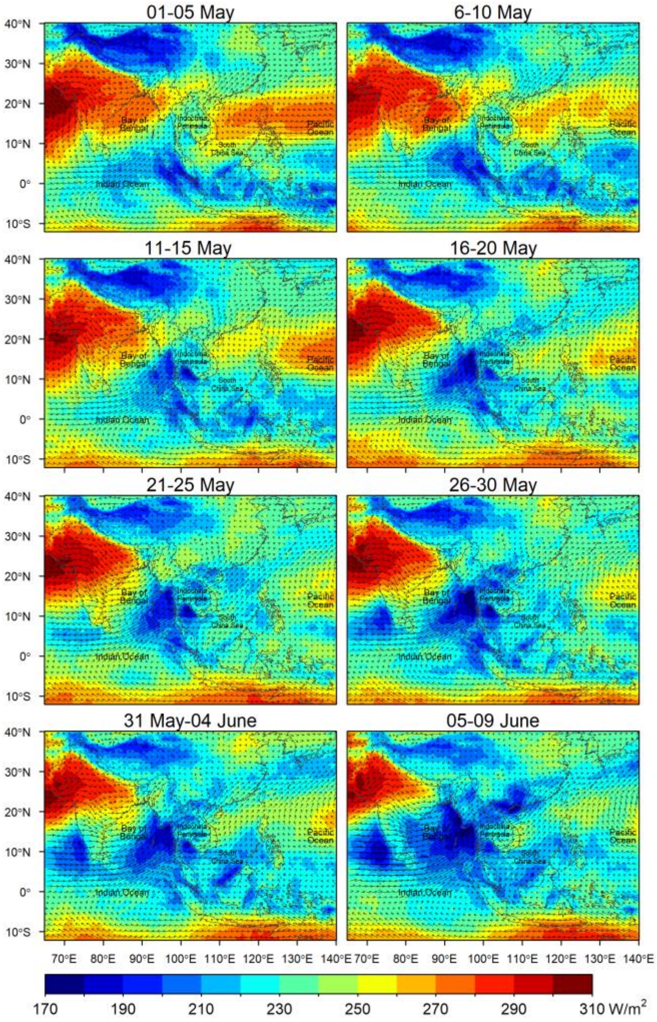

Fig. 3. Mean regional circulation and characteristics of the SWM withdrawal from 2000 to 2020 in the study region.

Based on the results of the present study, it appears that the study region does not undergo significant changes in OLR during monsoon onset and withdrawal, making it difficult to determine the timing of SWM based solely on this metric. In Malaysia, the monsoon onset is typically classified when OLR values rise above 220 W m^{-2} and the monsoon withdrawal when OLR values dip below 220 W m^{-2} [13]. However, it seems that in the study area, the OLR values (Figures 2 and 3) throughout the monsoon months are consistently higher than this threshold level. This presents a challenge in using OLR as a sole indicator to detect the monsoon onset and withdrawal. On the other hand, the Indochina Peninsula experiences notable OLR variations, with peak values occurring in late May to early June and late September to early October. This suggests that the monsoon season in the Indochina Peninsula is characterized by more significant fluctuations in OLR compared to the study region, suggesting the need for tailored approaches to monsoon onset and withdrawal detection in the study region. In a study by Hu et al. [16], it was proposed that the 850 hPa zonal wind is a superior indicator for detecting monsoon changes in the SCS region compared OLR. This suggestion stems from their discovery that the weakening of the ITCZ during SWM withdrawal leads to diminishing and retreating of southwesterly winds across the study area and the Indian Ocean.

3.2 *Variability of Southwest Monsoon Dates*

Based on the above-mentioned criteria, the time series of onset and withdrawal dates over ECPM waters from 2000 to 2020 exhibit significant interannual variability from year to year (Figure 4). The climatological mean indicates that the monsoon onset varies from May 8th to June 6th (day 128 to day 157), with a standard deviation of 8 days, which implies a range of temporal differences of around a week. Similarly, withdrawal dates vary from September 9th to October 13th (day 252 to day 286), with a standard deviation of about 9 days. For the study period, the average onset date of the SWM occurs on May 23rd and ends on September 27th. Furthermore, a substantial delay (> 5 days from the normal) occurs in 2003 and 2016, while 2018 is the year when onset experiences a significant advance. Similarly, the significant advance in monsoon retreat occurs in 2018, while the significant delay is found in 2006 and 2015. The duration of monsoon varies from year to year, lasting about 127 ±11 days annually. The shortest monsoon period occurs in 2016 (106 days), while the longest duration is observed in 2015 (146 days).

The average onset date of May 23rd was found to be later than recent study by Chenoli et al. [13] where their result shows May 19th as the mean onset. This different result may be caused by the larger study area they used whereas this study only focuses on one particular area instead of the whole Malaysia region. The mean onset date of SWM reported here also accords with our earlier observations (Figure 2), which shows a steady and persistent westerly regime during the fifth pentad of May (21-25 May). This finding is also reported by Luo and Lin [11], who discovered that the summer monsoon season begins when the westerly wind begins to dominate the region. Thus, the weather regime over the study region and nearby areas may be affected by these strong southwesterly winds. This is due to the fact that convective activity over the northern Sumatra turns north-eastwards over Indochina, allowing southwesterlies to penetrate the Peninsular Malaysia. Furthermore, the southeasterly wind linked with the western Pacific subtropical high is retreating eastward.

3.3 *Impact of ENSO*

It is widely recognized that ENSO is one of the most important factors modulating the interannual variation of the monsoon timing [11, 13, 31]. During the analysis period, there were three El Niño (2014, 2015 and 2019) and La Niña events

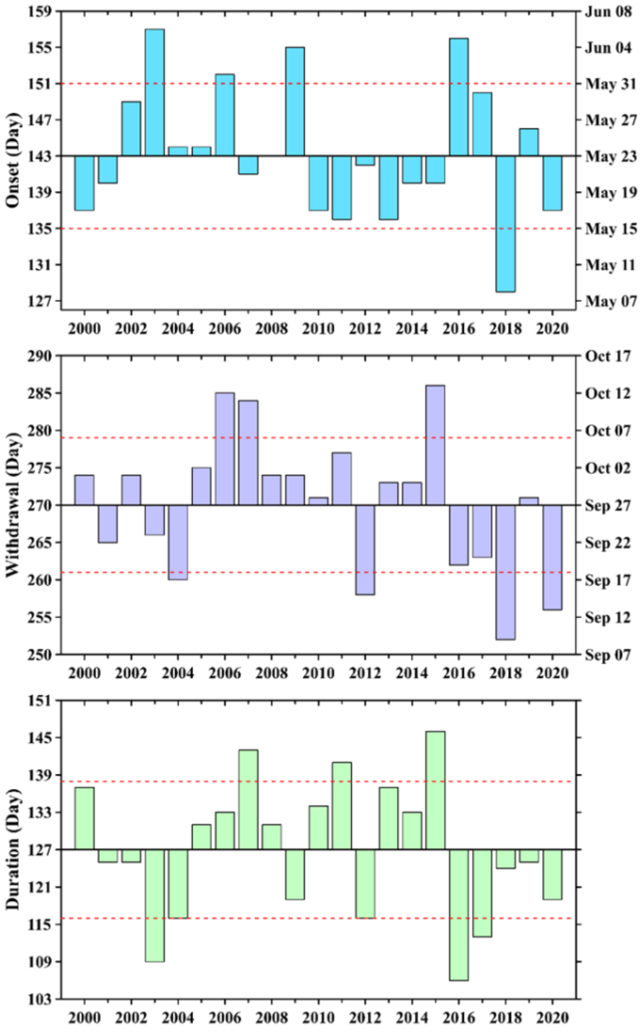

Fig. 4. Inter-annual variability of the SWM onset (top), withdrawal (middle) and duration of SWM (bottom) over the period 2000-2020. The dashed lines represent ±1 standard deviation which separates the early and late dates from the mean.

(2000, 2013 and 2008). Except for the El Niño in 2015, which was characterized by a strong SST anomaly (> 1.5 ºC), the other ENSO events featured weaker SST anomalies (±0.5 to ±0.9 ºC). In this study, we employed a 6-year-smoothed time series analysis to examine the influence of El Niño and La Niña events on the variability of monsoon onset dates. This approach was adopted to discern long-term patterns and trends, thereby providing a more comprehensive understanding of the impact of ENSO on the observed variability in the timing of the SWM onset. The relationship between SWM onset dates and Niño index is shown in Figure 5 and exhibits a significant positive correlation ($r = 0.63$, $p < 0.05$). This strong relationship suggests that El Niño events tend to be associated with a delay (advance) in SWM onset dates in the study area. This result agrees with those found by Fitzpatrick et al. [32] and, Moron and Robertson [33] where positive correlations were found between ENSO index and the SWM timing in the Bay of Bengal. However, compared with the SWM onset, the relationship is not much valid ($p > 0.05$; figure not shown) during the SWM withdrawal phase. This observation is consistent with findings from other studies (e.g., [34-35]), suggesting that the variation of SST during the monsoon withdrawal phase is not as pronounced as during the onset phase.

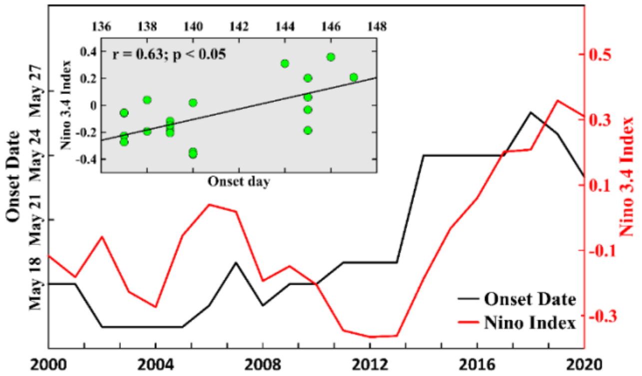

Fig. 5. Comparisons of onset dates and Niño 3.4 index from 2000 to 2020. The inset plot shows the relationship between the onset day and Niño 3.4 index.

In this section, we demonstrate the mechanism of how the two ENSO phases (El Niño and La Niña) could delay or advance the monsoon timing. To examine the diverse responses of different ENSO phases to the convective activities, the composite mean OLR and zonal wind at 850 hPa during 4 major events of La Niña (2000, 2007, 2008 and 2010) and El Niño (2002, 2004, 2015 and 2019), together with normal years (2001, 2003, 2012 and 2013) were analyzed. The circulation patterns and OLR distribution (Figure 6) show noticeable difference between SWM onset (May - June) and withdrawal (October - November) phases during El Niño and La Niña years. During El Niño years, the significant warming (high OLR) and weakening of easterly trade winds can be seen over the equatorial Pacific in both months, which reduces the amount of moisture transport towards the southern SCS region. As a result, the convective activity over the southern SCS is weakened (relatively high OLR as compared to normal years), leading to a delay in the onset and withdrawal of the SWM over the region. Conversely, during La Niña years, the easterly trade winds in the equatorial Pacific become stronger, which leads to the widespread and intensification of deep convection and the lowering of OLR over much of the study region. The strengthening of easterly trade winds also produces strong southwesterly winds during May – June (Figure 6 – left panel) and October - November (Figure 6 – right panel), leading an early onset and withdrawal of the SWM over the study region.

Several studies (e.g., [11, 13, 17, 36]) proposed that the strength and location of the subtropical high in the western North Pacific plays a critical role in regulating the timing and intensity of the Asian summer monsoon. According to the authors, the formation of a massive anomalous cyclonic and anticyclonic circulation in the low-level tropical western Pacific during different ENSO phases can effectively cause an advanced or a delayed onset/withdrawal of the summer monsoon. During the mature phase of El Niño, there is a tendency for the tropical western Pacific to experience anomalous warming and convection. This leads to the formation of a large-scale anomalous anticyclonic circulation over the western Pacific, which suppresses convection and rainfall over the region, resulting in a delay or weakening of the Asian summer monsoon.

Conversely, during the mature phase of La Niña, there is a tendency for the tropical western Pacific to experience anomalous cooling and convection. This results in the formation of a large-scale anomalous cyclonic circulation over the western Pacific, leading to enhance convection and rainfall over the region. The enhanced convection over the western Pacific during La Niña years may result in an early or strong onset of the Asian summer monsoon. However, it is important to note that weather patterns are complex and can be influenced by a variety of factors, and the relationship between ENSO and the SWM is not always straightforward or consistent. Further research may be needed to fully understand the extent of this relationship and its implications for regional climate patterns.

4. CONCLUSION

The present study uses a combined method based on zonal winds at 850 hPa and OLR to determine the onset and withdrawal dates of the SWM over the east coast of Peninsular Malaysia. The modified wind shear index calculated at the major convection centre (Bay of Bengal and Philippines waters) and OLR values greater (lesser) than 240 W m^{-2} are used to identify the onset (withdrawal) of the SWM. The study found that the SWM onset is manifested by the sudden acceleration of southerly winds in the Indian Ocean in mid-May while the retreating SWM wind can be recognized by the steady decrease of westerly winds from September until October. Based on these criteria, the mean of SWM onset and withdrawal dates was found to be May 23 and September 27, respectively.

The analysis of ENSO impact suggests that the interannual variation of SWM onset is correlated with ENSO event. Our results revealed that El Niño (La Niña) tends to have a late (early) onset date. The long-term change in SWM onset and withdrawal dates could potentially be influenced by other factors, and detailed analysis into how these factors influence the SWM timing warrants further research. Nevertheless, this study provides a better understanding of monsoon interannual variability that helps future research into the impact of climate change on monsoon timing.

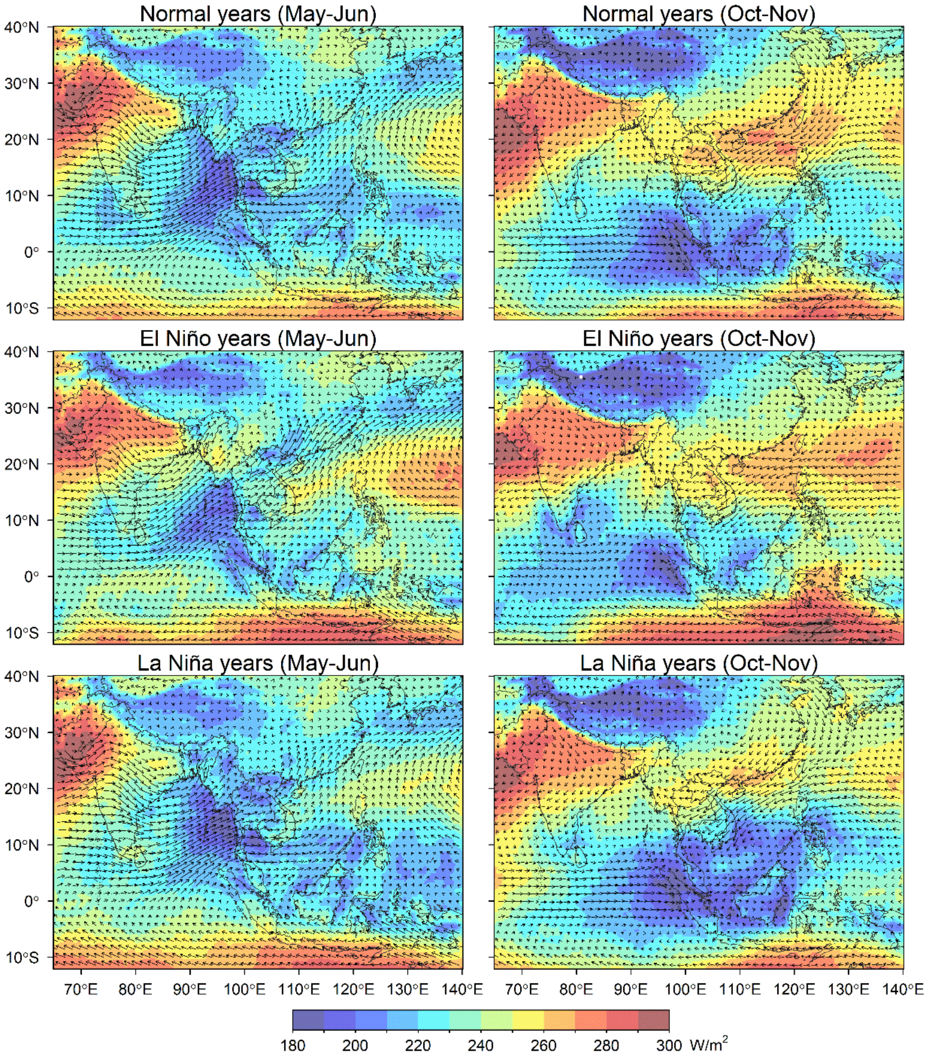

Fig. 6. General circulation and OLR trends in May-June (left panel) and October-November (right panel) during normal, El Niño and La Niña years. Four major El Niño (2002, 2004, 2015 and 2019), La Niña (2000, 2007, 2008 and 2010) and normal years (2001, 2003, 2012 and 2013) were selected to study the impacts of ENSO on OLR and wind circulation patterns.

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