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ANALYSIS OF THE NORTHEAST MONSOON 2016/2017

Fadila Jasmin Fakaruddin, Yip Weng Sang, Mat Kamaruzaman Mat Adam, Nursalleh K Chang and Muhammad Helmi Abdullah

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ABSTRACT

The 2016/2017 Northeast Monsoon (NEM) characteristics were reviewed using the methods introduced by Cheang (1980), Subramaniam et al. (2014), Chang et. al. (2005) and Hai et. al. (2017). The onset and withdrawal dates were discovered on 10th November 2016 and 11th March 2017, respectively. The NEM onset and withdrawal dates were categorised as near average, but the NEM duration is shorter than the average NEM period. This paper agrees with Subramaniam et al. (2014) that the shorter length of the NEM 2016/2017 is due the influence of the weak La-Nina episode. Four cold surges and five episodes of heavy rainfall were identified during this season. The first and second cold surges caused heavy rainfall episodes over Kelantan, Terengganu, Pahang, Johore and Sabah. However, relatively dry weather prevailed in the third and fourth surges. This paper also revealed that each heavy rainfall episodes during this NEM season occurred close to or within an easterly surge. The easterly surge was shown to have caused convergence with the easterly winds from the western north Pacific Ocean (WNP) and increased convection during the 4th and 5th episode of heavy rainfall. The role of cold surges, easterly surges, Borneo Vortex(BV), Madden-Julian Oscillation (MJO), El-Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) were reviewed and the interaction between these systems, largely determines the variability of the organized convection over the Malaysian region, as suggested by Tangang et. al. (2008). In addition to this, the tropical cyclone activities and their possible impact on rainfall, based on Munirah and Subramaniam (2009), were discussed for NEM 2016/2017.

1. INTRODUCTION

This paper reviewed the onset, withdrawal and period of cold surges of the NEM during the 2016/2017 season using the definitions and methods from Cheang (1980) and Subramaniam et. al. (2014). In addition to these, the method used by Chang et al. (2005) and Hai et. al. (2017) were adopted in this paper to calculate the cold surges and easterly surges during this NEM season.

As suggested by Tangang et. al. (2008), the relevance of the role of cold surges, easterly surges, BVs, MJO, IOD, ENSO and tropical cyclones (TC) during this NEM season was also discussed in this paper. The interaction between these systems largely determines the variability of the organised convection over the Malaysian region.

Chang et. al. (2005) suggested that the cold surge strengthens the northeasterly wind near the surface and the regional topography acts to restrict the flow as it is channelled towards the equator. Although the surge from the north is relatively cooler and drier, it becomes moister as it travels over the warmer surface of the southern South China Sea. It plays an important role in the episodes of enhanced deep convection over the equatorial South China Sea towards Malaysia.

Chang et. al. (2005) also revealed that during NEM season, there would be certain episodes where the strong easterly winds from the western north Pacific Ocean (WNP) (known as the easterly surges) were restricted and channelled towards the equator and hence contributed to the strengthening of the northeasterly winds over the southern South China Sea. The low-level winds then interacted with the terrain over the region and this resulted in a low-level convergence and widespread deep convection over Sumatra and southern Peninsular Malaysia.

The northeasterly cold surge often interacts with the synoptic scale disturbance known as the BV. Chang et. al. (2005) found that BV will enhance the convection and increase the low-level convergence over the southern South China Sea, but suppresses the convections over the surrounding regions.

On the intraseasonal timescale, the large-scale circulations over the Indian Ocean and Maritime Continent are very much influenced by the Madden-Julian Oscillation (MJO) event which was present during the NEM season. Depending on the phase of the MJO, the anomalous large-scale circulations associated with the Rossby wave-type responses may act to strengthen or weaken a cold surge event. Chang et al. (2005) indicated that the frequency of cold surges and vortex days is reduced during periods when MJO is active, that is when the MJO amplitude as calculated by Wheeler et al. (2004) exceeds 1. Generally, the primary impact of MJO is to inhibit weak cold surges which induces a secondary impact on the BV via interactions between the cold surge winds and the vortex.

In addition, the convection during NEM monsoon season is also influenced by the development of sea surface temperature over the Indian Ocean (IO), which is known as the Indian Ocean Dipole (IOD). Chang et. al. (2005) agreed that the convection during NEM monsoon distributed by the anomalous cooler sea surface temperature (SSTA) (negative IOD) over the southeastern Indian Ocean, which suppresses the convection over that particular region and enhances convection over Malaysian region.

Climatologically, Malaysia experiences normal or slightly above normal rainfall during the peak of an El-Nino event. Subramaniam et. al. (2014) revealed that ENSO seems to have a large influence on the length of the monsoon season, where during El-Nino years, the season is longer, while during La-Nina the season is shorter. Northeasterly cold surges also show large variations, with fewer cold surges during El-Nino years compared to the average (five cold surges per season).

Furthermore, although dry (wet) precipitation extremes are generally enhanced during El-Nino and La-Nina occurrences, this is dependent on the season and location, and their influences are non-linear. Tangang et al. (2017) observed that strong (moderate) La-Nina causes a significant decrease (increase) in wet precipitation extremes over Peninsular Malaysia. In short, the likelihood of widespread flooding over the east coast of Peninsular Malaysia during December-January-February (DJF) increases during moderate but not during strong La-Nina events.

2. DATA

The Japanese 55-year Reanalysis (JRA55; Kobayashi et al. 2015) dataset provided by the Japanese Meteorological Agency (JMA) was used in this paper for the index calculation and wind depiction. The daily rainfall data were obtained from meteorological stations operated by the Malaysian Meteorological Department (MMD).

MJO and IOD data were obtained from the Bureau of Meteorology, Australia (BOM). The ENSO index were taken from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC), http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). Meanwhile, the tropical cyclone dates and track were obtained from JMA through their regional typhoon centre, The Regional Specialized Meteorological Center (RSMC), Tokyo.

3. RESULT AND DISCUSSION

3.1 Onset of the NEM 2016/2017

The onset of the NEM 2016/2017 was calculated using the criteria derived by Subramaniam et. al. (2014) and Cheang (1980). According to Subramaniam et. al. (2014), the Northeast Monsoon Index (NEMI) is equal to the mean zonal wind component between 925-hPa and 850-hPa averaged over the region as depicted in **Figure 1 (red box)**.

Cheang (1980) used a combination of wind and rainfall to define the onset of NEM in Malaysia. In his study, Cheang (1980) used the 850-hPa wind at Kota Bharu Meteorological Station to compute the Wind Steadiness Index (WSI). WSI is determined by taking the ratio of the magnitude of the mean vector wind over a time period to the mean wind speed over the same period. The time period used is 30 days and WSI is computed for every successive 30-day period starting from 1st October. WSI is calculated using the formula below:

$$WSI = \frac{\sqrt{(\bar{u})^2 + (\bar{v})^2}}{\overline{\sqrt{u^2 + v^2}}}$$

u – zonal wind component (daily);

v – meridional wind component (daily);

$\bar{u}$, $\bar{v}$ – mean zonal, meridional wind component up to 30 days ahead; and

$\overline{\sqrt{u^2 + v^2}}$ – mean of the scalar (magnitude) wind up to 30 days ahead

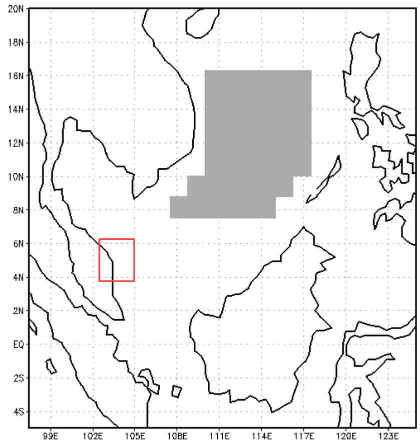

Figure 1: Red box indicates the region used for computing the onset and withdrawal of NEM, while the grey region indicates the area used to compute the cold surges

Therefore, based on Cheang (1980) and Subramaniam et. al. (2014), the NEM onset is said to occur when:

i. NEMI remains negative (shows that easterlies prevailing) for 7 days with at least 1 day less than -2.5 m/s. (Subramaniam et. al., 2014); and

ii. WSI exceeds 0.7 and at the same time at least one of the principal meteorological stations along the east coast of Peninsular Malaysia has recorded a cumulative rainfall starting from 1st October of at least 3 inches or 76.2 mm (Cheang, 1980).

To determine the onset of the NEM 2016/2017, the NEMI was plotted in **Figure 2,** while the WSI was plotted in **Figure 3.**

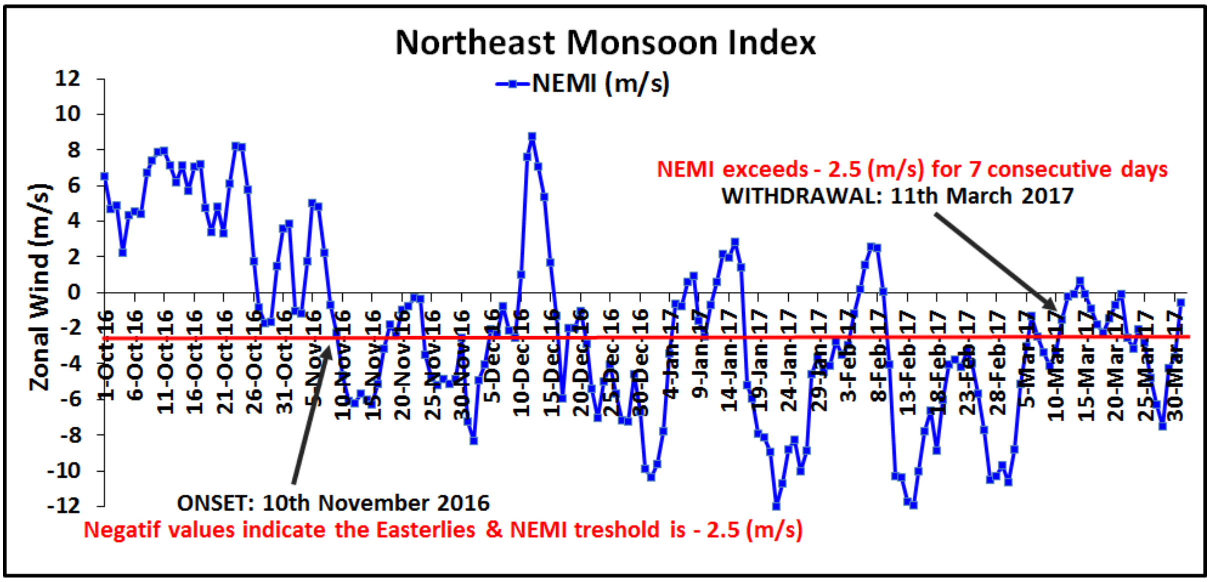

Figure 2: NEMI showed sustained negative values starting from 10th November 2016 and exceeding – 2.5 m/s on 11th March 2017 for 7 consecutive days, which indicated the onset and withdrawal of the NEM 2016/2017 respectively.

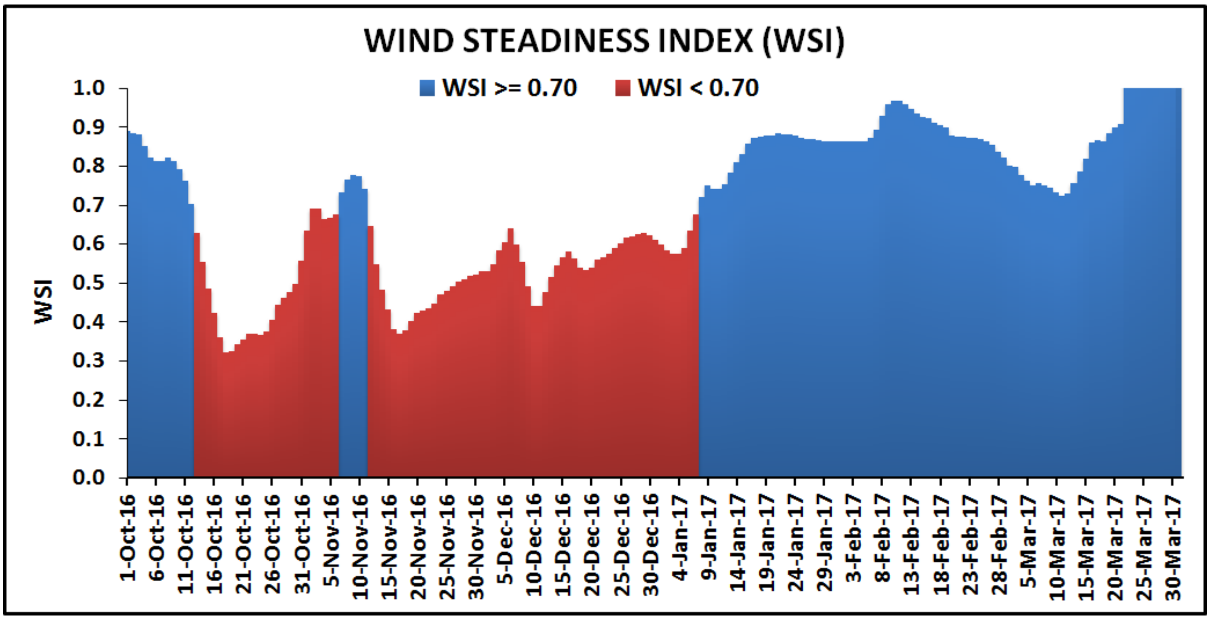

Figure 3: The WSI values sustained 0.7 and above indicating the NEM (blue shaded).

NEMI analysis in **Figure 2** shows the sustained negative values starting from **10th November 2016**, which indicates the **onset of the NEM 2016/2017**. The onset date was near to the average onset date as compared to the climatological onset date (7th November).

The wind steadiness index analysis in **Figure 3** showed values of 0.7 and above indicating the NEM (blue shaded). Based on this analysis, a few values exceeded 0.7 which indicated the NEM. However, there were also a few values less than 0.7 during October until December 2016, which showed inconsistent WSI as described by Cheang (1980). In this analysis, we found that the WSI was hardly defining the onset of the NEM 2016/2017 due to the variable winds. The winds changes were attributed to the influence of eight strong tropical cyclones over the western north Pacific Ocean (WNP) during October until December 2016, which were higher than the average occurrence (seven), based on RSMC-Tokyo Typhoon Centre Data from the year 1981 - 2010. The details of tropical cyclones during NEM 2016/2017 and their intensities will be discussed further in **Section 3.8.**

3.2 Withdrawal of the NEM 2016/2017

The withdrawal date of the NEM 2016/2017 was also calculated from the method of Subramaniam et. al. (2014) and Cheang (1980). Based on these methods the NEM withdrawal is said to occur when:

i. NEMI exceeds -2.5 m/s for 7 consecutive days and westerly wind component (positive value) starts to penetrate the Malaysian region (Subramaniam et. al., 2014); and
ii. WSI drops below 0.7 and remains so for more than 7 days (Cheang, 1980)

Based on the NEMI analysis, on **11th March 2017**, the value started to exceed -2.5 m/s and sustained for 7 consecutive days, which indicated the **withdrawal of the NEM 2016/2017.** It was near to the average withdrawal date as compared to the climatological withdrawal date (18th March). The NEM 2016/2017 lasted for 121 days. Its duration was shortest than the average NEM length which was 132 days (Subramaniam et. al., 2014). The WSI value remained more than 0.7 from January 2017 onwards, hence it cannot be used to determine the NEM withdrawal date. The low WSI value in October - December this season implies that wind speed and direction were more highly variable compared to previous years. More study needs to be done on wind variability during NEM.

3.3 The Role of Northeast Cold Surges/ Easterly Surges

This paper used the Cold Surge Index (CSI) adopted from Subramaniam et. al. (2014) to calculate the number of cold surges during this NEM season. To determine the intensity of the cold surges, the average wind speed at the 1000-hPa level over the region shown in **Figure 1** (grey shaded) was computed. A cold surge is said to occur when the wind speed exceeds 20 knots and remains so for at least 3 days. However, in the case of the first surge of the season, the episode is counted as a cold surge if the difference in wind speed at more than 20 knots persist for less than 3 consecutive days. The CSI based on Subramaniam et. al. (2014) is depicted in **Figure 4**.

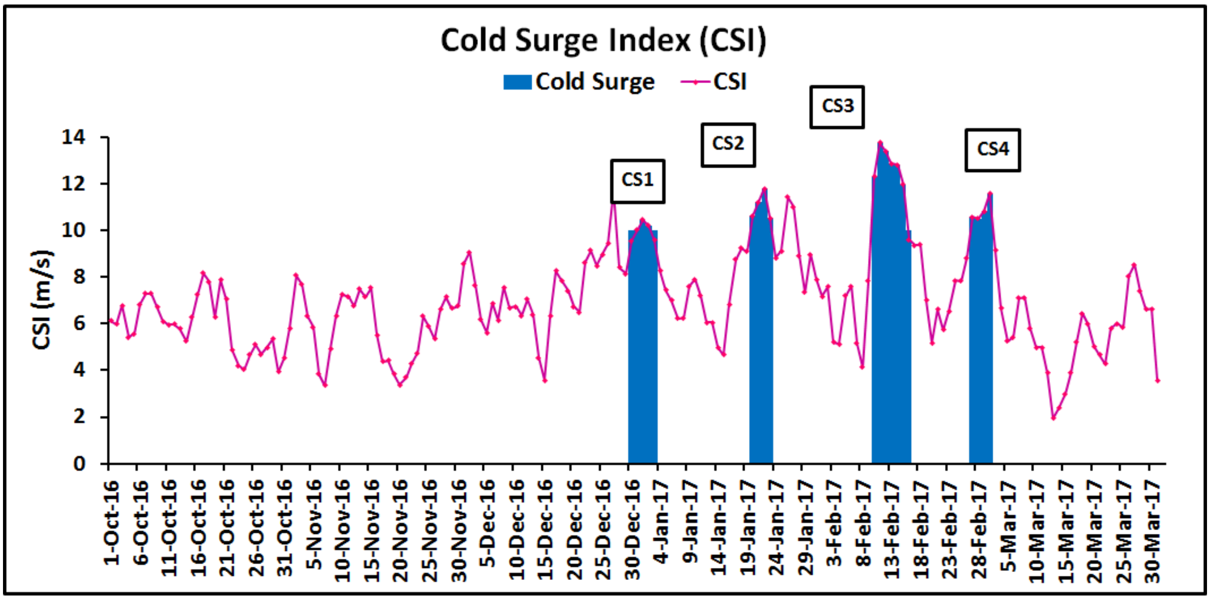

Figure 4: The Cold Surge Index (CSI) during NEM season 2016/2017. A cold surge is said to occur when the wind speed exceeds 20 knots and remain for at least 3 days (depicted by the blue shaded).

Based on this analysis, four surges occurred during NEM 2016/2017. The first surge occurred on 30th December 2016, which was 35 days later than the average first surge (25th November). The second surge occurred on 20th January 2017, which was 21 days after the first surge. Meanwhile, the third and fourth surges occurred on 10th and 27th Feb 2017, respectively. The CSI and rainfall amount for East Coast states of Peninsular Malaysia (Kelantan, Terengganu, Pahang and eastern Johore), Sabah and Sarawak during NEM 2016/2017 season were plotted in **Figure 5**.

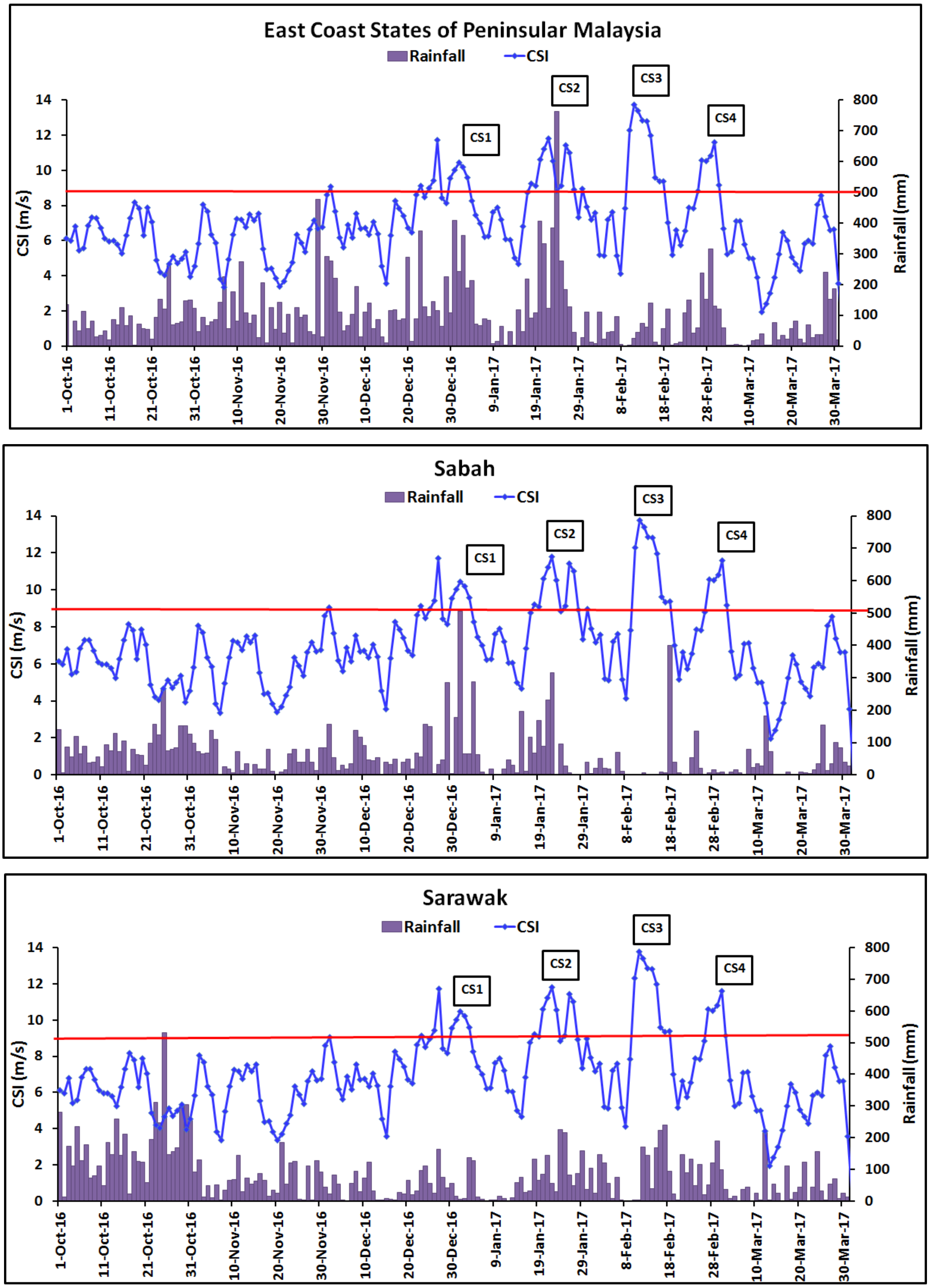

Figure 5: The CSI and rainfall amount for East Coast states of Peninsular Malaysia (Kelantan, Terengganu, Pahang and Eastern Johore), Sabah and Sarawak during NEM 2016/2017 season.

In addition to the CSI defined based on the criteria of Subramaniam et al. (2014), this report also used another cold surge index, Meridional Cold Surge Index (MSI) which was adopted from the method used by Chang et al. (2005) to determine the cold surges during NEM season. MSI is defined as the averaged 925-hPa meridional wind between 110° and 117.5°E along 15°N as depicted in **Figure 6** (black region).

By adapting the index definition from Chang et. al. (2005), Hai et. al. (2017) defined the easterly surge index (ESI), which is the zonal wind surge due to the strengthening or equatorward movement of the subtropical ridge over the northwestern Pacific as a result of a Siberian high outbreak, as the averaged 925-hPa zonal wind between 7.5°N and 15°N along 120°E as depicted in **Figure 6** (grey region). Easterly surges were found to have enhanced the precipitation during NEM season.

A cold surge event (easterly surge) is said to occur when the MSI (ESI) exceeds 8 m/s. Furthermore, the surge intensity was divided into weak, moderate and strong categories for surge index values between 8 and 10 m/s, 10 and 12 m/s, and greater than 12 m/s respectively in accordance with Chang et al. (2005).

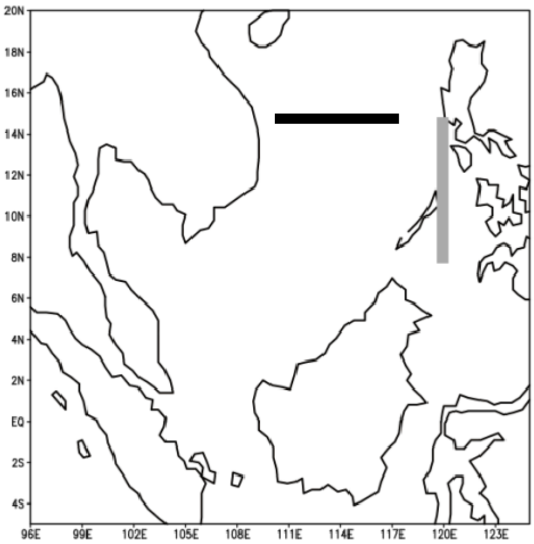

Figure 6: The black region indicates the area use to calculated the MSI by Chang et. al. (2005), while the grey region indicates the area used to compute the ESI from Hai et. al. (2017).

Cold surges modulate the impact of deep convection in South East Asia during the Boreal Winter. Chang et. al. (2005) observed that during non-surge periods deep convection lies over Indochina while reduced convection is found over the equatorial South China Sea region. However, during surge days, an opposite pattern happens whereby enhanced convection is observed over the equatorial South China Sea but reduced convection over Indochina.

Based on the MSI and ESI there were 9 easterly surge episodes and 5 meridional surge episodes. Four out of five (4/5 or 80%) of the easterly surge episodes which occurred before the month of February 2017, happened in conjunction with heavy rainfall episodes in Malaysia. One out of three (1/3 or 33%) of the meridional surge episodes that were observed before the month of February 2017, happened together with heavy rainfall episodes in Malaysia and an easterly surge episode. The remaining four (4) easterly surges and two (2) meridional surge after the month of February 2017 did not happen in together with any heavy rainfall episodes in Malaysia. In summary, the easterly surges were more closely associated with heavy rainfall episodes in Malaysia compared to meridional surges in the 2016/17 NEM. **Figure 7** depict both the easterly and meridional cold surges together with heavy rain days.

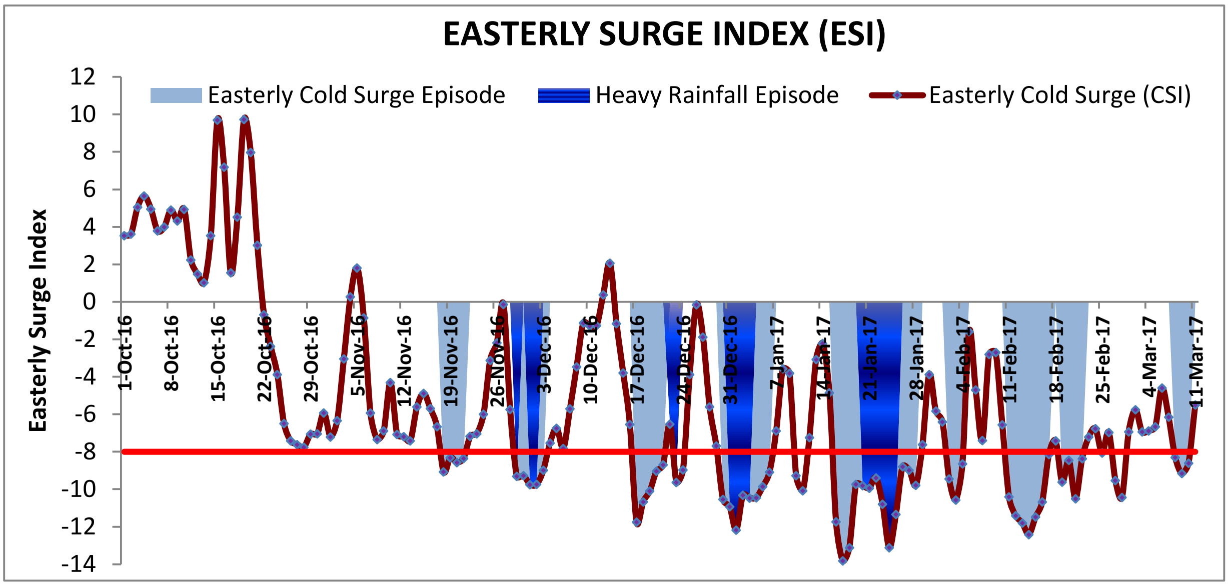

Figure 7a: The easterly surge index and heavy rainfall episodes during the NEM 2016/2017 season. Easterly surges episodes were considered to have occurred when the easterly cold surge index exceeds 8 m/s for at least 3 consecutive days. All heavy rainfall episodes occurred close to or within an easterly cold surge episode during the 2016/17 NEM.

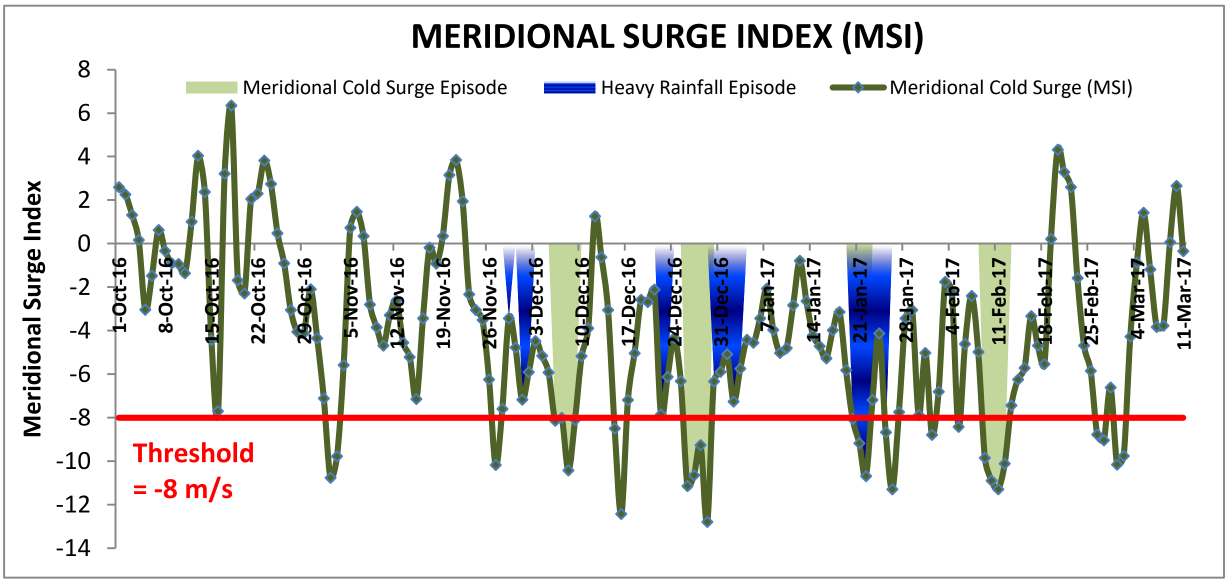

Figure 7b: The meridional surge index and heavy rainfall episodes during the NEM 2016/2017 season. Meridional surges episodes were considered to have occurred when the meridional cold surge index exceeds 8 m/s for at least 3 consecutive days. Only one (1) heavy rainfall episode occurred close to or within a meridional cold surge episode during the 2016/17 NEM.

3.4 The Role of BV

The northeasterly cold surge often interacts with the synoptic scale disturbance found in the vicinity of the island of Borneo, known as the BV. Chang et. al. (2005) found that BV will enhance the convection and increase the low-level convergence over the southern South China Sea, but suppresses the convections over the surrounding regions.

The BV is said to have occurred whenever a closed counter-clockwise circulation on the 925-hPa wind field within the area of 107.5°E – 117.5°E, 2.5°S – 7.5°N is observed. The region of interest was depicted in the rectangular black box in **Figure 8**. This criteria was also used in Chang et al. (2005).

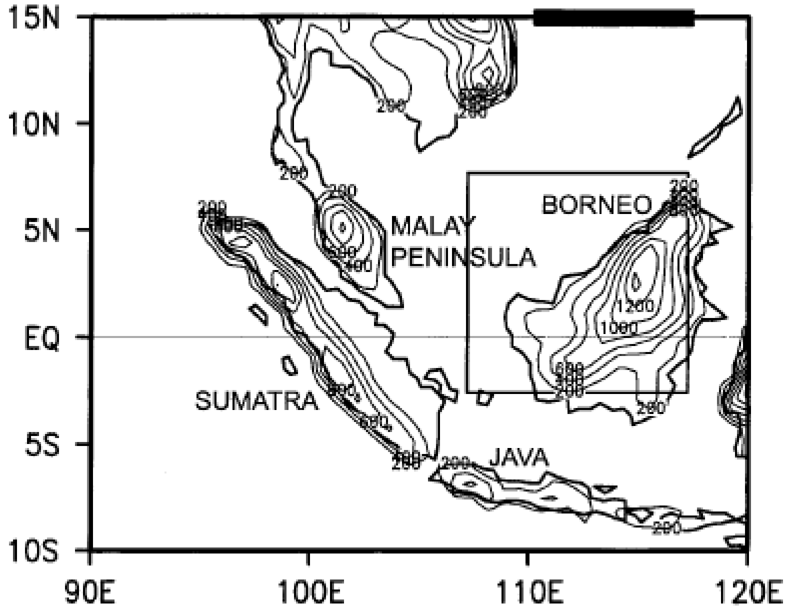

Figure 8: The BV is identified within the rectangular black box.

The vortex days per month during the 2016/17 NEM was shown in **Figure 9.** Fifty-seven vortex days were recorded throughout the 2016/2017 NEM. The highest frequency falls in December at a total of 19 vortex days or one-third (35%) of the total vortex days during the 2016/2017 NEM. The second highest frequency was observed in January at 11 vortex days or approximately one-fifth (20%) of the 2016/2017 NEM. The remaining months (November, February, March) showed the least frequency at 8 vortices days each. In a nutshell, the early and later part of the NEM 2016/2017 showed less BV occurrences compared to the middle part of the NEM 2016/2017.

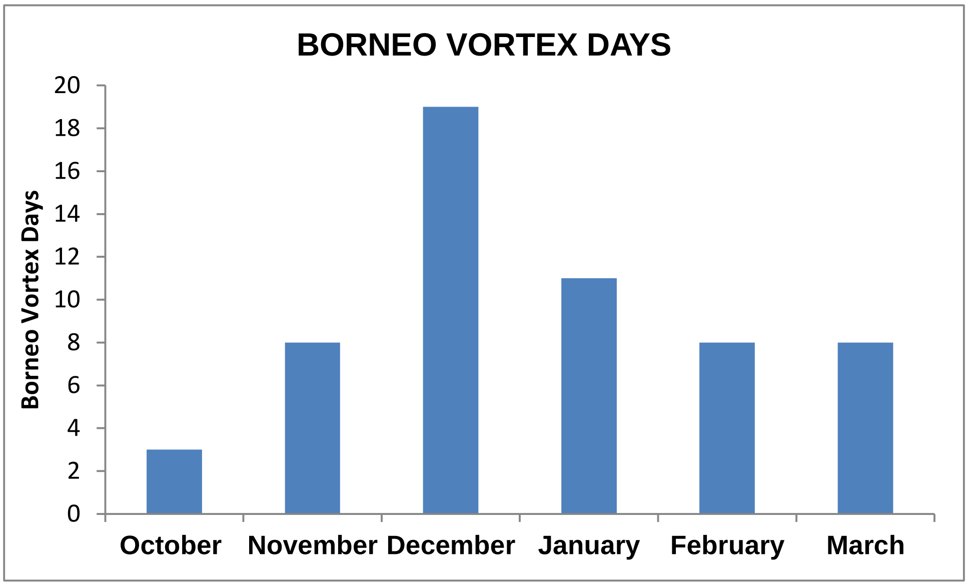

Figure 9. The BV frequency/ days during the NEM 2016/2017 season.

Both the BV and cold surge together modulate rainfall in our region as observed during the two longest heavy rainfall spell in Malaysia which lasted four days from 31st December 2016 to 3rd January 2017 and six days from 20th to 25th January 2017.

In the first case, both the CSI and the ESI registered a cold surge event, but the BV was absent in most days. Heavy rainfall was confined to Peninsular Malaysia. However, during the second case, both indices also registered a cold surge with a BV in most days. Severe rainfall was recorded in the Peninsular East Coast and also Sabah (north Borneo). **Table 7** depicts and describes each heavy rainfall episode.

In a nutshell, this observation agrees with the findings of Chang et al. (2005) whereby low-level convergence was shifted towards the Borneo Island. Additionally, both the CSI and ESI together show potential forecast skill in detecting relatively longer heavy rainfall episodes with the condition that cross-equatorial flow is absent.

Table 1 depicts the heavy rainfall dates, BV dates, ESI dates and intensities, MSI dates and intensities, and the significant MJO episodes.

HEAVY RAINFALL DATES	BV DATES	ESI DATES	ESI INTENSITY	MSI DATES	MSI INTENSITY	MJO PHASES
	7 Oct					
	26 – 27 Oct					
	2 – 3 Nov					
	11 Nov					7
	12 Nov					8
		18 Nov	Weak			1
		19 – 21 Nov				2
	25 Nov					3
	27 Nov					3
	28 Nov					
29 Nov		29 Nov	Weak			
	30 Nov	30 Nov	Weak			
1 – 2 Dec		1 – 2 Dec	Weak			
	3 Dec	3 Dec	Weak			
	5 Dec					
	6 – 9 Dec			6 – 9 Dec	Weak	
	10 Dec					4
	17 – 18 Dec	17 – 18 Dec	Moderate			
	19 Dec	19 Dec	Moderate			6
	20 – 21 Dec	20 – 21 Dec	Weak			6
22 Dec						6
23 Dec	23 Dec	23 Dec	Weak			
	24 Dec	24 Dec	Weak			
	25 Dec					
	26 – 27 Dec			26 – 27 Dec	Moderate	
				28 Dec	Weak	
				29 Dec	Strong	

HEAVY RAINFALL DATES	BV DATES	ESI DATES	ESI INTENSITY	MSI DATES	MSI INTENSITY	MJO PHASES
	30 Dec	30 Dec	Moderate			
31 Dec		31 Dec	Moderate			
1 Jan		1 Jan	Strong			3
2 Jan		2 Jan	Moderate			3
3 Jan	3 Jan	3 Jan	Moderate			
		4 Jan	Moderate			
		5 – 6 Jan	Weak			
		10 Jan	Weak			5
		11 Jan	Moderate			5
		16 Jan	Moderate			
	17 Jan	17 Jan	Strong			1
		18 Jan	Strong			1
		19 Jan	Moderate			1
20 Jan	20 Jan	20 Jan	Moderate	20 Jan	Weak	1
21 Jan	21 Jan	21 Jan	Moderate	21 Jan	Weak	2
22 Jan		22 Jan	Moderate	22 Jan	Moderate	2
23 Jan	23 Jan	23 Jan	Moderate	23 Jan	Weak	2
24 Jan	24 Jan	24 Jan	Strong	24 Jan	Weak	2
25 Jan		25 Jan	Moderate	25 Jan	Moderate	2
		26 Jan	Weak	26 Jan	Weak	3
		27 – 28 Jan	Weak			3
	29 Jan					3
	30 Jan – 1 Feb					4
	2 Feb	2 Feb	Weak			5
	3 Feb	3 Feb	Moderate			5
		4 Feb	Weak			5
				9 Feb	Weak	7
		10 Feb	Moderate	10 Feb	Moderate	7
		11 Feb	Moderate	11 Feb	Moderate	7

HEAVY RAINFALL DATES	BV DATES	ESI DATES	ESI INTENSITY	MSI DATES	MSI INTENSITY	MJO PHASES
		12 Feb	Moderate	12 Feb	Weak	7
		13 Feb	Moderate			8
		14 Feb	Strong			8
		15 Feb	Moderate			8
	16 Feb	16 Feb	Moderate			8
		17 Feb	Weak			1
		19 Feb	Weak			1
	20 Feb	20 Feb	Weak			2
		21 Feb	Moderate			2
	22 Feb	22 Feb	Weak			2
	23 Feb					2
	25 Feb	25 Feb	Weak			2
				26 Feb	Weak	2
		27 Feb	Moderate	27 Feb	Weak	2
		28 Feb	Weak	28 Feb	Weak	2
	1 – 2 Mar			1 – 2 Mar	Weak	3
		8 – 9 Mar	Weak			4
		10 Mar	Weak			3
	12 – 13 Mar					4
	24 Mar					
	27 Mar					3
	28 Mar					4
	30 Mar					3

3.5 The Role of MJO

According to Chang et al. (2005), on the intra-seasonal timescale, the large-scale circulations over the Indian Ocean and Maritime Continent were very much influenced by the MJO event which was present during the NEM season. Depending on the phase of the MJO, the anomalous large-scale circulations associated with the Rossby wave-type responses may act to strengthen or weaken a cold surge event. They indicated that the frequency of cold surges and vortex days is reduced during periods when MJO is present. Generally, the primary impact of MJO is to inhibit weak cold surges and to impact on the BV.

Chang et. al. (2005) also revealed that during MJO periods, more cold surges occur on the MJO Phase 3 and 4 than on Phase 1 and 2. During MJO Phase 1, the BV most likely occurs without a surge, while during MJO Phase 2, the low-level wind associated with the Borneo vortex are more organised. Meanwhile, during MJO Phase 3, the MJO enhanced convection and equatorial westerlies extended throughout the Maritime Continent.

Using the data from BOM, this study only considered major MJO events, which were defined whereby the amplitude of WH04 index (Wheeler et al., 2004) is greater than 1 by Hidayat et al. (2010). Since the MJO is a propagating convective system, the major MJO events enhanced the convection and provide more available moisture to the weather systems over the area they are passing.

There were 98 days of significant MJO events recorded from October 2016 until March 2017. MJO phases 4 and 5 reflect enhanced convection over the Maritime Continent including Malaysia (Wheeler et al., 2004). The highest number of occurrence day for MJO phases 4 and 5 were during October 2016 and March 2017 (seven days respectively). The details of major MJO events was depicted in **Table 2.**

Table 2: Major MJO events from October 2016 until March 2017. The cold surge episode (MSI) is shown as the shaded plot

Month	Date	No. of days	Phase
October	1 – 5	5	5
	6	1	5
	13	1	5
	20	1	3
November	4 – 5	2	5
	6 – 7	2	6
	8 – 11	4	7
	12 – 15	4	8
	16 – 18	3	1
	19 – 22	4	2
	23 – 27	5	3
December	10	1	4
	19 – 22	4	6
January	1 – 2	2	3
	9 – 11	3	5
	17 – 20	4	1
	21 – 25	5	2
	26 – 29	4	3
	30 – 31	2	4
February	1	1	4
	2 – 6	5	5
	7 – 8	2	6
	9 – 12	4	7
	13 – 16	4	8
	17 – 19	3	1
	20 – 28	9	2
Mac	1 – 4	4	3
	5 – 9	5	4
	10	1	3
	11 – 12	2	4
	27	1	3
TOTAL NO. OF DAYS		**98**	

From this analysis, we found that two surge occurred without the presence of MJO, two surges occurred during MJO Phase 1 and 2 and one surge occurred during MJO Phase 7.

Twenty-eight out of fifty-seven (28/ 57) or nearly half of BV days happened in days without MJO while another half occurred during an active MJO period. The impact of the MJO towards BV frequency was not clearly observed during the 2016/2017 NEM.

Meanwhile, 63% of easterly surges (ESI) and 85% of cold surges (CSI) happened in conjunction with an active MJO period. Forty-three percent of easterly surges (Chang et. al., 2005) and half of surge days (Subramaniam et. al., 2014) occurred in MJO phases 2 and 3. Wheeler et al. (2004) have observed that MJO phases 2 and 3 show southerly wind anomalies. Their occurrences during the surges may oppose the northerly meridional surge component leading to the lack of meridional surges observed during the NEM 2016/2017.

The BV days, CSI and ESI frequencies per MJO phase are tabulated in **Table 3**.

Table 3: Major MJO events (Phase 1-8) and no-MJO periods (0) from October 2016 to March 2017 with the heavy rainfall, BV, CSI and ESI frequencies (days) for each MJO phase.

MJO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**0**
Heavy Rainfall Days	1	5	2	0	0	1	0	0	6
BV Days	2	8	6	4	2	3	1	2	29
Cold Surge (based on NEMI)	1	5	4	0	0	0	3	4	3
Easterly Surge (based on ESI)	4	10	6	2	5	3	2	4	22

3.6 The Role of El-Nino Southern Oscillation (ENSO)

Climatologically, Malaysia experiences normal or slightly above normal rainfall during the peak of El-Nino event. Subramaniam et. al. (2014) revealed that ENSO seems to have a large influence on the length of the monsoon season, where during El-Nino years, the season is longer, while during La-Nina the season is shorter. Northeasterly cold surges also show large variations, which have fewer cold surges during El-Nino years compared to the average (five cold surges per season).

Based on the centred 30-years base periods which are updated every 5 years by NOAA, the ONI from the year 2016 to 2017 were plotted in **Table 4**. A weak La-Nina episode occurred in conjunction with the NEM 2016/2017 during the first half of the season, meanwhile neutral conditions occurred in the second half of the season.

Table 4: ONI showed weak La-Nina had occurred during the first half of NEM 2016/2017 season, meanwhile neutral conditions occurred in the second half of the season. Cold periods (showed by blue) indicated the La-Nina episodes, while the warm periods (showed by red) indicated the El-Nino episodes.

Month/ Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2016	2.2	2.0	1.6	1.1	0.6	0.1	-	-	- 0.8	- 0.8	- 0.8	- 0.7
2017	-	-										

NEMI analysis in **Figure 2 (page 5)** discovered that 10th November 2016 and 11th March 2017 were the onset and withdrawal date of the NEM 2016/2017. It was near to the average onset and withdrawal date as compared to the climatology (Subramaniam et. al., 2014). The season lasted for 121 days, where its duration was shorter than the average NEM length which is 132 days. As NEM 2016/2017 was influenced by the weak La-Nina, thus this analysis agreed with Subramaniam et. al. (2014) that NEM 2016/2017 has a shorter than the average length of NEM.

3.7 The Role of IOD

Chang et. al. (2005) described that the convection during NEM season is influenced by the development of sea surface temperature over the Indian Ocean (IO), which is known as the IOD. They agreed that the convection during NEM distributed by the anomalous cooler sea surface temperature (SSTA) (negative IOD) over the southeastern Indian Ocean, which suppressed the convection over that particular region and enhanced convection over Malaysian region.

NEM 2016/2017 season was during the IOD neutral condition for the whole period. Therefore, the influence of the IOD on Malaysian climate was weak during this period. Positive IOD indicates cooler than normal water in the eastern and warmer than normal water in the western tropical Indian Ocean. This condition increased the convection over the Indian Ocean and BOB. Generally, this means there is less moisture than normal in the atmosphere over the Malaysian region. Meanwhile, negative IOD indicates warmer than normal water in the east and cooler than normal water in the west of tropical Indian Ocean. Thus, this condition caused suppressed convection over the Indian Ocean and BOB and typically provide more available moisture to the weather systems over Malaysia.

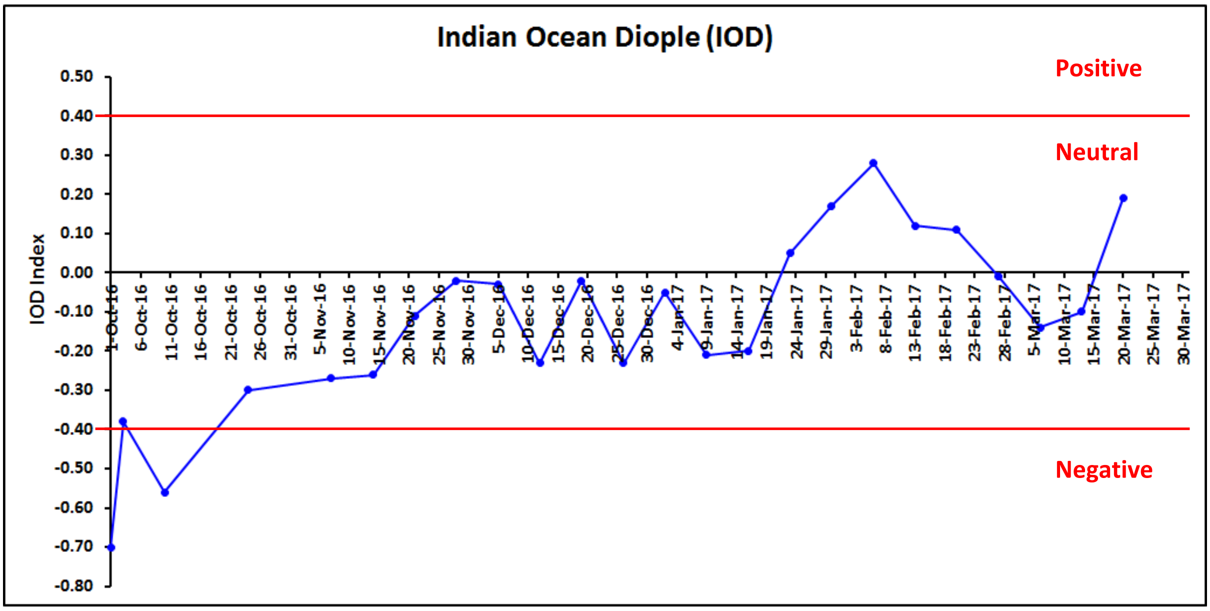

Figure 10: IOD from October 2016 until March 2017

3.8 The Role of Tropical Cyclone (TC)

Malaysia is located close to the western north Pacific Ocean (WNP) and within the South China Sea (SCS) region. Both WNP and SCS are one of the most active cyclogenesis regions in the world. They have the highest number of tropical cyclones with an average of 27 cyclones per year, with nearly half of them reaching typhoon intensity. Tropical cyclones (TCs) are intense synoptic systems that significantly modifies the basic atmospheric state through the entire troposphere. This has a strong influence on the regional rainfall pattern, even to countries that are not directly on the path of these cyclones. In November – December the monsoon trough extends from the western Pacific, between 5°N and 10°N, to southern SCS, between the equator and 8°N. In consonance with the equatorward displacement of the trough, the TC activity gets shifted equatorward and closer to the Malaysian region. In the late boreal winter months; January to March, few cyclones develop in the WNP. During this period, the monsoon or near equatorial trough is generally located south of the equator. However, occasionally cyclogenesis takes place in the WNP between 5°N and 15°N when there exists a double near-equatorial trough. These storms generally track westwards and very few intensify to become typhoons. (Munirah and Subramaniam, 2009).

The impact of TCs in the WNP and SCS on the rainfall in Malaysia have been studied by Munirah and Subramaniam (2009). It was found that TCs have a significant impact on rainfall in Peninsular Malaysia as well as in East Malaysia. It was observed that northern Borneo (Sabah) has a higher chance of getting rain when the TC is on the open seas while northwestern Borneo (Sarawak) has an increased chance of rainfall when the TCs are in the SCS. Northwestern Peninsular Malaysia has a higher probability of getting rain during TC landfall or close to Indochina. The intensity of the TCs were found to increase rainfall probability in general.

NEM 2016/2017 witnessed eight occurrences of the strong tropical cyclones over the western north Pacific Ocean (WNP) during October until December 2016, which were higher than the average occurrence (seven according to RSMC-Tokyo).

The highest intensity of the tropical cyclone belonged to Haima, which was classified as a Violent Typhoon (based on the RSMC, Tokyo scales). The list of the tropical cyclone over the WPO during NEM 2016/2017 were depicted in **Table 5**.

Table 5: The list of the tropical cyclone over the WNP during NEM 2016/2017

	Name	Category	Date	Maximum wind near the centre (knots)
1.	Aere	Severe Tropical	5 – 10 Oct 2016	60
2.	Songda	Very Strong Typhoon	8 – 13 Oct 2016	100
3.	Sarika	Very Strong Typhoon	13 – 19 Oct 2016	95
4.	Haima	Violent Typhoon	15 – 21 Oct 2016	115
5.	Meari	Typhoon	3 – 7 Nov 2016	75
6.	Ma-On	Tropical Storm	10 – 12 Nov 2016	35
7.	Tokage	Severe Tropical	25 – 28 Nov 2016	50
8.	Nock-Ten	Violent Typhoon	21 – 27 Dec 2016	105

No TCs over the WNP coincided with the five heavy rainfall episodes during the 2016/2017 NEM. Additionally, effects of surges, MJO and extreme rainfall upon cyclogenesis and TC development over the Maritime Continent have not been yet been studied as of now.

The study by Munirah and Subramaniam (2009) found significant variability in the rainfall over different parts of the Peninsular when the TCs in the BOB are either located north or south of 15°N. When the TCs are located south of 15°N, the northwestern parts of the Peninsular Malaysia seem to have a reduced chance of rain whereas the northeastern parts have an increased chance of rain, compared to when the TCs are located north of 15°N, during the primary cyclone season (October to December). Additionally, it was observed by Munirah and Subramaniam (2009) that the chance of getting heavy rainfall decreases as the cyclones intensify. The list of TCs over the BOB during NEM 2016/2017 were depicted in **Table 6**.

Table 6: The list of the tropical cyclone over the Bay of Bengal (BOB) during NEM 2016/2017

	Name	Category	Date (2016)	Maximum wind near the centre (knots)	Comment
1.	Kyant	Cyclonic storm	21 – 28 Oct	46	North of 15°N
2.	-	Depression	3 – 6 Nov	24	North of 15°N
3.	Nada	Cyclonic storm	29 Nov – 2 Dec	40	South of 15°N
4.	Vardah	Very severe cyclonic storm	6 – 13 Dec	70	South of 15°N
5.	-	Depression	17 – 18 Dec	24	South of 15°N

Only cyclonic storm Nada (29th November – 2nd December 2016) coincided with a heavy rainfall episode in the northeastern Peninsular Malaysia (29th November, 1st – 2nd December 2016). Nada also developed to the south of 15°N. Although this agreed with the findings of Munirah and Subramaniam (2009) that BOB TCs south of 15°N tended to increase heavy rainfall probability in the northeastern Peninsular Malaysia, more long-term study on TC interaction with the surges as well as rainfall distribution is needed to draw any conclusion.

3.9 Rainfall Episode

Five episodes of heavy rainfall occurred during this season. Each of the heavy rainfall episodes coincided with an easterly surge. The freshening of easterly winds from the western Pacific Ocean and convergence with northerly winds from mainland Asia during an easterly surge brings about enhanced convection and heavy rainfall over Malaysia.

The surge criteria according to Subramaniam et al. (2014) coincided with two out of five heavy rainfall episodes while no meridional surges were observed during the 2016/2017 NEM.

All surge criteria used in this report including the easterly surge and cold surge according to Subramaniam et al. (2014) were dry during the late NEM 2016/2017 or February 2017 onwards. This was attributed to cross-equatorial wind flow over Malaysia caused by the position of the monsoon trough at the equator. Cross-equatorial flow diverts moisture away from Malaysia to the southern Hemisphere leading to enhanced convection in Sumatra and Java. The lower and upper tropospheric wind flow during the late period of the 2016/2017 NEM was consistent with climatology (long-term average). The rainfall episodes of the NEM 2016/2017 season was summarised in **Table 7.**

Table 7: The surges, rainfall episodes and rainfall description of the NEM 2016/2017 season

No.	Surge Date (Subramaniam, 2014)	Surge Date (CP Chang, 2005; Easterly surge)	Rainfall episode
1.	-	29 – 30 Nov 2016 (weak)	<u>**29 November 2016**</u> • The first episode of heavy rainfall over Malaysia affecting Terengganu in the east coast of Peninsular Malaysia • Weak easterly surge • Monsoon trough between 0° to 5°N • Broad easterlies from the western Pacific Ocean • Strong northerlies from mainland Asia and the northern Pacific Ocean • Convergence between easterly and northerly winds along the monsoon trough in the Peninsular Malaysia east coast lead to enhanced convection • The heaviest rainfall amount on 29 Nov 2016 was recorded in Kuala Terengganu, Terengganu (225 mm).

No.	Surge Date (Subra, 2014)	Surge Date (CP Chang, 2005; Easterly surge)	Rainfall episode
2.	-	1 – 3 Dec 2016 (weak)	**1 – 2 December 2016** • The second episode of heavy rainfall over Malaysia impacting Kelantan and Terengganu • Weak easterly surge • Monsoon trough between 0° to 5°N • Northerly wind from the Asian mainland converging with Pacific easterlies • Convergence to the north of a cyclonic vortex in the Peninsular east coast • The heaviest accumulated rainfall amount during this episode was recorded in Kota Bharu, Kelantan (285 mm).
3.	-	17 – 19 (Moderate) 20 – 21, 23 – 24 (Weak surge) Dec 2016	**22 – 23 December 2016** • The third episode of heavy rainfall over Malaysia which impacted Kelantan and Terengganu • Moderate (before) to weak (during and after episode) easterly surge • Monsoon trough between 0° to 5°N • Convergence to the north of the monsoon trough axis of the northerlies from mainland Asia and easterlies from the Pacific in the east coast of Peninsular Malaysia • The heaviest accumulated rainfall amount was recorded in Kota Bharu, Kelantan (261mm).

No.	Surge Date (Subra, 2014)	Surge Date (CP Chang, 2005; Easterly surge)	Rainfall episode
4.	30 Dec 2016 – 3 Jan 2017	30 – 31 Dec 2016 (Moderate) 1 Jan (Strong) 2 – 4 Jan (Strong) 5 – 6 Jan 2017 (Weak)	**30 December 2016 – 3 Jan 2017** • This was the fourth episode of heavy rainfall over Malaysia which affected Kelantan and Terengganu • This episode was characterised by an intense surge with strong easterly component originating from an anticyclone in the Yellow Sea • Convergence of the easterly winds to the north of the monsoon trough located between 0° to 5°N lead to enhanced convection over the east coast of Peninsular Malaysia • The heaviest accumulated rainfall amount during this episode was recorded in Kuala Krai, Kelantan (557 mm).

No.	Surge Date (Subramaniam, 2014)	Surge Date (CP Chang, 2005; Easterly surge)	Rainfall episode
5.	20 – 23 Jan 2017	20 – 22 Jan 2017 (Moderate surge) 24 Jan 2017 (Strong surge) 25 Jan 2017 (Moderate surge) 26 – 28 Jan 2017 (Weak surge)	**<u>20 – 25 January 2017</u>** • This was the fifth episode of heavy rainfall over Malaysia which impacted Kelantan, Pahang, Johore and Sabah • The BV was observed on 20 – 21 and 23 – 24 January 2017 • Easterly surge strength was strong to moderate in conjunction with the cold surge according to Subra • The northerly surge from mainland Asia recurved to a more easterly direction due to the subtropical ridge position along 20°N • The northeasterly winds converged to the north of the monsoon trough between 0° to 5°N in the Peninsular East Coast • Additionally, the broad easterlies were also observed to converge in Borneo (the BV was seen) • The heaviest accumulated rainfall amount during this episode was recorded in Kudat, Sabah (723 mm).

No.	Surge Date (Subra, 2014)	Surge Date (CP Chang, 2005; Easterly surge)	Rainfall episode
6.	10 – 16 Feb 2017 27 Feb – 2 Mar 2017	2 – 4 Feb 2017 10 – 17 Feb 2017 19 – 22 Feb 2017 25 Feb 2017 27 – 28 Feb 2017 8 – 10 Mar 2017	**<u>Dry Surges</u>** • Both the subtropical ridge and the monsoon trough has marched south as winter progresses • The subtropical ridge position lies around 20°N to 25°N while the monsoon trough is located around 0° • Northeasterly winds recurve along a more northerly direction as it crosses to equator to the southern hemisphere • As a result, moisture from the cold surges is diverted to the southern hemisphere leading to enhanced convection along Sumatra, Java, and northern Australia leaving our region dry.

Based on the mean climatological rainfall data from the year 1946 until 2014, all states recorded average amount of rainfall during October 2016. However, Kelantan and Johore recorded slightly (20% to 40%) below average rainfall during November 2016. During December 2016, Kelantan and Sabah recorded slightly above average rainfall, while Pahang (slightly), Johore (40% to 60%) and Sarawak (slightly) recorded below average amount of rainfall. January 2017 witnessed Kelantan, Terengganu, Pahang and Sabah received 60% more rainfall compared to their January average. In February 2017, Kelantan, Pahang, Johore and Sarawak still received above average amount of rainfall. However, the amounts were slightly lower as compared to January 2016. Meanwhile, during March 2017, most of the station recorded average amount of rainfall, except for Terengganu and Sabah, which received slightly below average and 40% to 60% above average amount of rainfall respectively.

The comparison between monthly and climatological rainfall data for the east coast states of Peninsular Malaysia (Kelantan, Terengganu, Pahang and Eastern Johore), Sabah and Sarawak were plotted in **Figure 11**.

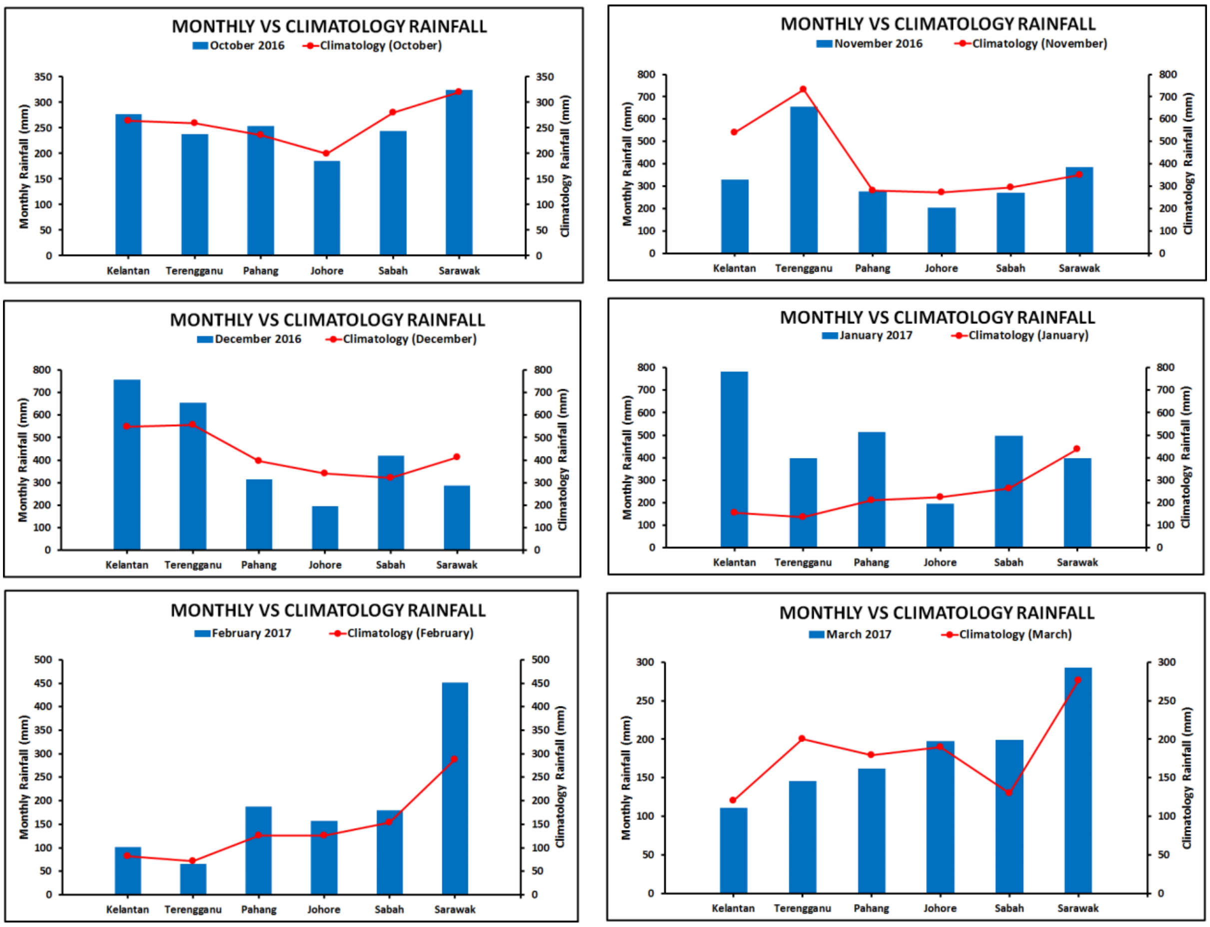

Figure 11: The comparison between monthly and climatological rainfall data for east coast states of Peninsular Malaysia (Kelantan, Terengganu, Pahang and Eastern Johore), Sabah and Sarawak

4. SUMMARY

This paper discovered that 10th November 2016 and 11th March 2017, were the onset and withdrawal dates of the NEM 2016/2017 respectively. These date were near to average onset and withdrawal dates, but NEM duration was shorter than the average NEM period. This paper agreed that the shorter length of the NEM 2016/2017 was due the influence of the weak La-Nina episode which occurred in conjunction with the NEM 2016/2017 during the first half of the season. Although the NEMI (Subramaniam et al., 2014) successfully determined the NEM 2016/2017 onset date, the WSI (Cheang, 1980) failed to determine the onset date. More study is needed to investigate the anomalously variable winds leading to low WSI during this season.

Four surges occurred during NEM 2016/2017, where the first surge only occurred on 30th December 2016, which was 35 days later than the average first surge.

Five episodes of heavy rainfall occurred during this season. Two heavy rainfall episodes corresponded to the cold surges from Siberia while three other episodes coincided with the easterly surges from the WNP. However, dry weather prevailed in surges from February 2017 onwards. This condition was due to the presence of cross-equatorial flow as a result of the southward shift of the subtropical ridge and monsoon trough in the northern hemisphere. According to Cheang (1980), the southward movement and the subsequent disappearance of the near-equatorial trough indicate cross-equatorial flow over Peninsular Malaysia. In February and March 2017, the monsoon trough was located along the equator while the subtropical ridge was observed along 20°N. Climatologically, both synoptic features were located in their southernmost position in a year. The position of the subtropical ridge and the monsoon trough causes the northeasterly wind from the Pacific Ocean and mainland Asia to cross the equator into the southern hemisphere. Moisture is diverted from the northern hemisphere to southern hemisphere leading to enhanced convection in Sumatra, Java and southern Australia but drier conditions in the equatorial South China Sea.

Additionally, an ESI and MSI adapted from Chang et al. (2005) were used in this report. The easterly surge index was found to coincide with each heavy rainfall episode during the 2016/2017 NEM. No meridional surge was detected during this season. The cold surge index from Subramaniam et al. (2014) in conjunction with the easterly surge index may hold some predictive skill in heavy rainfall outlook because the two longest heavy rainfall spell occurred when both indices indicated a surge.

The presence of a Borneo vortex during the longest heavy rainfall spell in the season may have led to enhanced rainfall in northern Borneo due to moisture transport and low-level divergence being shifted towards Borneo in the presence of the Borneo vortex, in accordance with the findings of Chang et al. (2005).

Even though Chang et al. (2005) have noted that both cold surge frequency and Borneo vortex occurrences tend to be suppressed during an active MJO episode, in this season it was observed that the impact of active MJO was not apparent towards both cold surges and BV frequency. This discrepancy may be because Chang (2005) studied an inter-seasonal time-scale (21 boreal winters) whereas this report concerns an intra-seasonal period (one season; 2016/2017 NEM).

The lack of meridional cold surges this winter may be explained in this report. Around half of cold surges occurred in active MJO phases 3 and 4 which show southerly wind anomalies over the Maritime continent. This balances out the northerly component of the cold surges leading to no record of meridional surges detected according to the criteria laid by Chang et al. (2005).

In short, cold surges and easterly surges together lead to heavy rainfall episodes in Malaysia this season while the presence of the BV was shown to have shifted low-level convergence to northern Borneo resulting in heavy rainfall there. Persistent cross-equatorial flow on February 2017 onwards have to lead to dry surges in Malaysia. The weak La-Nina phase in the first half of the NEM 2016/2017 was shown to have slightly shortened the duration of the season. However, the effects of the MJO upon surge and Borneo vortex frequency were not apparent. This report summarises the major synoptic features that modulated the NEM 2016/2017.

The onset/withdrawal dates during the 2016/2017 NEM was successfully determined according to the NEMI index, however, the WSI index has failed, possibly due to anomalously variable winds than usual. Additional cold surge indices namely the CSI, MSI and ESI yielded different or no (MSI) surge dates, though the ESI may have more correlation with heavy rainfall episodes, this season. Therefore, a more robust cold surge index must be used to distinguish between dry and wet surges in future NEM reports.

5. REFERENCES

Chang, C.-P., P.A. Harr, and H.-J. Chen, 2005: Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. Mon. Wea. Rev., 133, 489-503, doi:10.1175/MWR-2868.1.

Cheang Boon Khean, 1980: Some Aspects of Winter Monsoon and Its Characteristics in Malaysia. Research Publication No. 2, Malaysian Meteorological Department

Hai, O. S., Samah, A. S., Chenoli, S. N., Subramaniam, K., A.Mazuki, M. Y., 2017: Extreme Rainstorms that Caused Devastating flooding across the East Coast of Peninsular Malaysia during November and December 2014. AMS, doi: 10.1175/WAF-D-16-0160.1

Kobayashi, S., Y.Ota, Y. Harada, A. Ebita, M. Moriya, H. Onoda, K. Onogi, H. Kamahori, C. Kobayashi, H. Endo, K. Miyaoka, and K. Takahashi, 2015: The JRA-55 Reanalysis: General Specification and Basic Characteristics. J. Meteor. Soc. Japan, 93, doi: 10.2151/jmsj.2015-001.

Munirah, A., M. Subramaniam, 2009: The Impact of Tropical Cyclones in the Western Pacific Ocean and South China Sea on the Rainfall in Malaysia. Research Publication No. 5 / 2009, Malaysian Meteorological Department.

Munirah, A., M. Subramaniam, 2010: The Impact of Tropical Cyclones in the Bay of Bengal on the Rainfall in Peninsular Malaysia. Research Publication No. 7 / 2010, Malaysian Meteorological Department.

RSMC Tokyo – Typhoon Center, 1999: Climatology of Tropical Cyclones. Retrieved April 2017 from http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/climatology.html

Subramaniam Moten et al., 2014: Statistics of the Northeast Monsoon Onset, Withdrawal and Cold Surges in Malaysia, Guidelines 2014, Malaysian Meteorological Department

Tangang, F. T., Liew, J., Salimun, E., Vinayachandran, P. N., 2008: On the Role of the Northeast Cold Surge, the Borneo Vortex, the Madden-Julian Oscillation, and the Indian Ocean Dipole during the extreme 2006/2007 flood in southern Peninsular Malaysia, Geo. Res. Let., 35, L14S07, doi:10.1029/2008GL033429

Tangang, F.T., et al., (2017): Characteristics of Precipitation Extremes in Malaysia Associated with El Niño and La Niña Events, International Journal of Climatology, doi: 10.1002/joc.5032

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