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Post-Mortem of
Northeast Monsoon 2019/2020

Nur Zu Ira Bohari, Wan Fariza Mustafah,
Diong Jeong Yik, Nursalleh K. Chang,
Yip Weng Sang and Azlai Ta'at

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By
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Post- Mortem of Northeast Monsoon 2019/2020

Nur Zu Ira Bohari, Wan Fariza Mustafah, Diong Jeong Yik,
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Abstract

The onset and withdrawal date of NEM 2019/2020 respectively were on 14 November 2019 and 18 March 2020. The onset date has fall within the average onset date. But the withdrawal date was strayed away from the average withdrawal date which is 16 May 2020. The withdrawal date was chosen considering on the synoptic features not followed by Northeast Monsoon Index (NEMI) index. The date and period of monsoon surges was calculated using Meridional Surge Index (MESI) and the total of 11 of surges were observed during NEM 2019/2020 with 3 Meridional Surge (MS), 7 Easterly Surge (ES) and 1 Mixed Surge (MES). The highest duration of surges was 14 days in the seventh surge (ES). Meanwhile, the lowest duration of surge was 3 days in the fifth surge (MES) and the eleventh surge (ES). From these surges, only episode 4, 6 and 7 of surge showed the daily accumulated rainfall exceed 150mm. The total number of TC occurred through this NEM season was seven (7) which three (3) of them form during the surges. Compared to all TC occurred, only TC Kammuri coincided with a heavy rainfall episode (Episode 4) in the northeastern Peninsular Malaysia (28 November - 8 December 2019). Overall, the other surges were declared as dry surge due to the non-existence significant rainfall. The El-Niño Southern Oscillation (ENSO) continued to remain in the neutral state. There are eight (8) MJO events were occurred in Phase 4 and 5 but only three (3) MJO events were occurred during the cold surge of NEM monsoon 2019/2020. The Indian Ocean Dipole (IOD) is slightly positive but continues to weaken and a return to neutral state starting in the middle of December 2019.

1.0 Introduction

This report reviews the onset, withdrawal, and period of cold surges of the Northeast Monsoon (NEM) during the 2019/2020 season. The daily analysis included rainfall and monsoon surges by regions in Malaysia. The monsoon system over Malaysia is characterized by wind patterns rather than the rainfall distribution as delineated by Ramage (1971). The NEM season in Malaysia is due to the prevailing northeasterly winds occurring from November until March that dominates the lower troposphere synoptic circulation. The monsoon has a significant impact on Malaysian weather (Moten et al., 2014).

2.0 Methodology

This section explains and provide details of all the data and methods used in this report. The data includes the daily rainfall recorded by the observation stations by the Malaysian Meteorological Department's (MET Malaysia). The data also included wind and mean sea level pressure (MSLP) that were obtained from the Japanese 55-years Reanalysis (JRA-55) dataset provided by the Japan Meteorological Agency (JMA) and quantitative daily precipitation from satellite observations obtained from NASA's Global Precipitation Measurement (GPM) (Huffman et al., 2019). In addition, the data of the Tropical Cyclone best track data (1951 - 2019) was obtained from the Regional Specialized Meteorological Center (RSMC) - Tokyo that documents the formation, movement, and development of tropical cyclones (TC) of the Western North Pacific within the framework of the World Weather Watch (WWW) Program of the World Meteorological Organization (WMO). The atmospheric circulations and the anomalies plots were plotted using the GrADS (Grid Analysis and Display System) program.

2.1 Onset and Withdrawal of the NEM 2019/2020

The Global Reanalysis Wind, the Japanese 55-years Reanalysis (JRA-55) dataset provided by the JMA were used in this report to objectively define the onset and withdrawal dates as well as the episode of surges. The onset and withdrawal of the NEM 2019/2020 were objectively calculated using the criteria proposed by Moten et al. (2014).

Northeast Monsoon Index (NEMI) was obtained by using the average zonal wind component at 925-hPa and 850-hPa over a blue box as shown in **Figure 1**. The onset of the NE monsoon occurs if the easterly wind component is sustained for at least seven days, and at least with one day where the speed is greater than 5 knots (2.5m/s). Meanwhile, the withdrawal of the NEM is said to have taken place when the easterly wind component has weakened to less than 2.5m/s for seven consecutive days and the westerly wind component (positive value) starts to penetrate the Malaysian region (Moten et al., 2014).

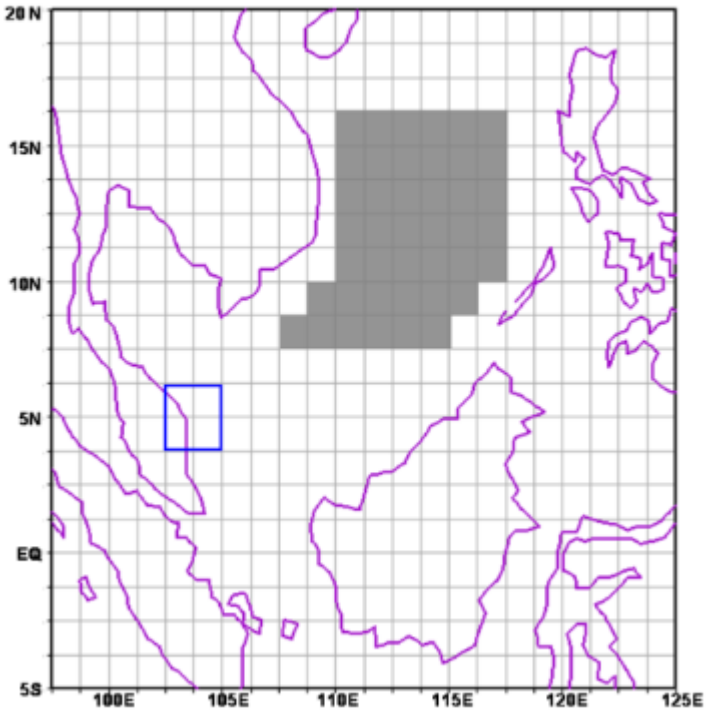

Figure 1: Blue box area at 3.75° N to 6.25° N and 102.50° E to 105.00°E used for computing the onset and withdrawal of NEM and grey region used for computing the cold surge. (Moten et al. 2014)

2.2 Monsoon Surges of the NEM 2019/2020

The definitions of the meridional surge (MS) and easterly surge (ES) were adopted from Chang et al. (2005) and Hai et al. (2017). The cold surge index from Chang et al. (2005) was calculated to detect all the surge events based on outbreaks of cold air outburst from the Siberian High moving towards the equatorial South China Sea (SCS). By adapting the index definition from Chang et al. (2005), the ES was defined due to the strengthening or equatorward movement of the subtropical ridge in the northwestern Pacific as a result of a Siberian High outbreak Raman et al. (1978).

For the surge calculation, the method used by Chang et al. (2005) and Hai et al. (2017) were adopted to calculate the Meridional Surge Index (MSI and Easterly Surge Index (ESI) during this NEM 2019/2020 period. MSI was calculated as the average of 925 hPa meridional winds bounded by 110°E to 117.5°E along 15°N, while ESI was calculated as the average of 925 hPa zonal winds between 7.5°N and 15°N along 120°E. A MS/ES event was said to occur when this index exceeded 8 m/s for at least three consecutive days. For the MES, it was considered when MS and ES occurred concurrently. The Mixed Surge (MES) is defined when MS and ES occurred simultaneously.

2.3 Synoptic Plots

The synoptic plots in every figure starts from episode of surge 1 to 11 that were plotted using GrADS program as illustrated in Figure 8 to Figure 18. The types of the data used for synoptic plots included GPM satellite data in NetCDF format, MSLP and wind in GrADS CTL file. While, an anomaly of an average rainfall was calculated by removing DJF (stands for December January, and February) long-term TRMM Mean Data (1997 – 2020).

3.0 Results and Discussion

3.1 Onset and Withdrawal NEM 2019/2020

The onset and withdrawal of NEM 2019/2020 were both determined using the above-mentioned method known as the North East Monsoon Index (named NEMI from here on). The onset and withdrawal date for NEM 2019/2020 season were on 14 November 2019 and 16 May 2020, respectively as shown in **Figure 2**. The onset date falls within the normal range of the climatological onset, which was consistent with Moten et al. (2014) as shown in **Figure 3**. However, the withdrawal date calculated from NEMI was beyond the average withdrawal date, March 18, 2020. This was due to the easterly wind captured by NEMI that was from the Pacific Ocean and not from the high-pressure system found mid-latitude, as shown in **Figure 4**. In addition to NEMI, subjective analysis of synoptic low-level wind was carried out to determine both onset and withdrawal date of NEM 2019/2020.

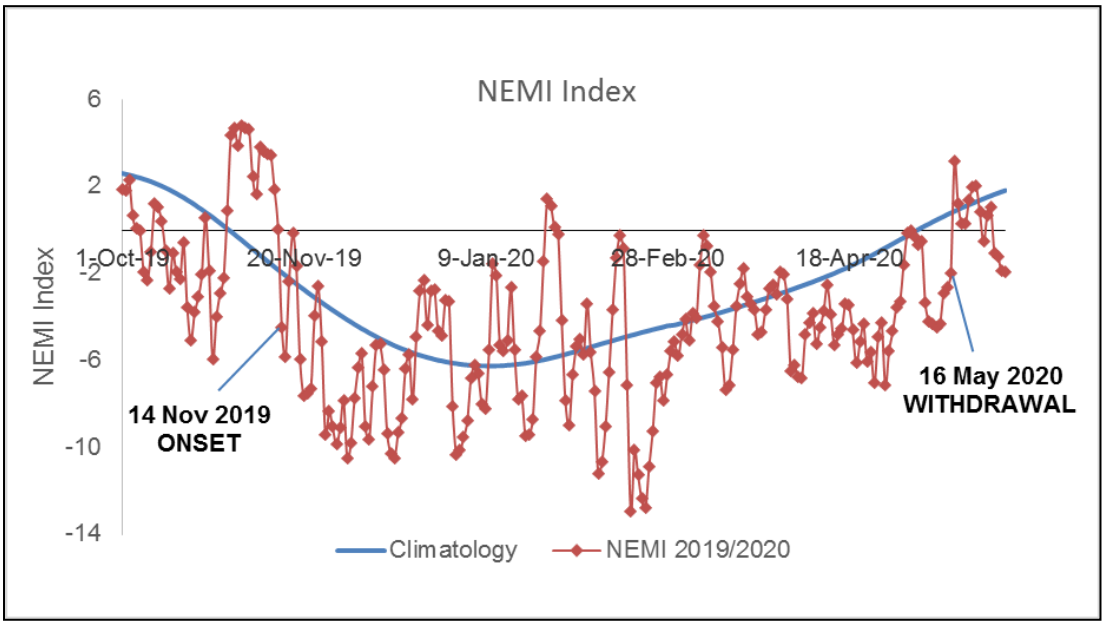

Figure 2: Onset and withdrawal date calculated based on Northeast Monsoon Index (NEMI) only

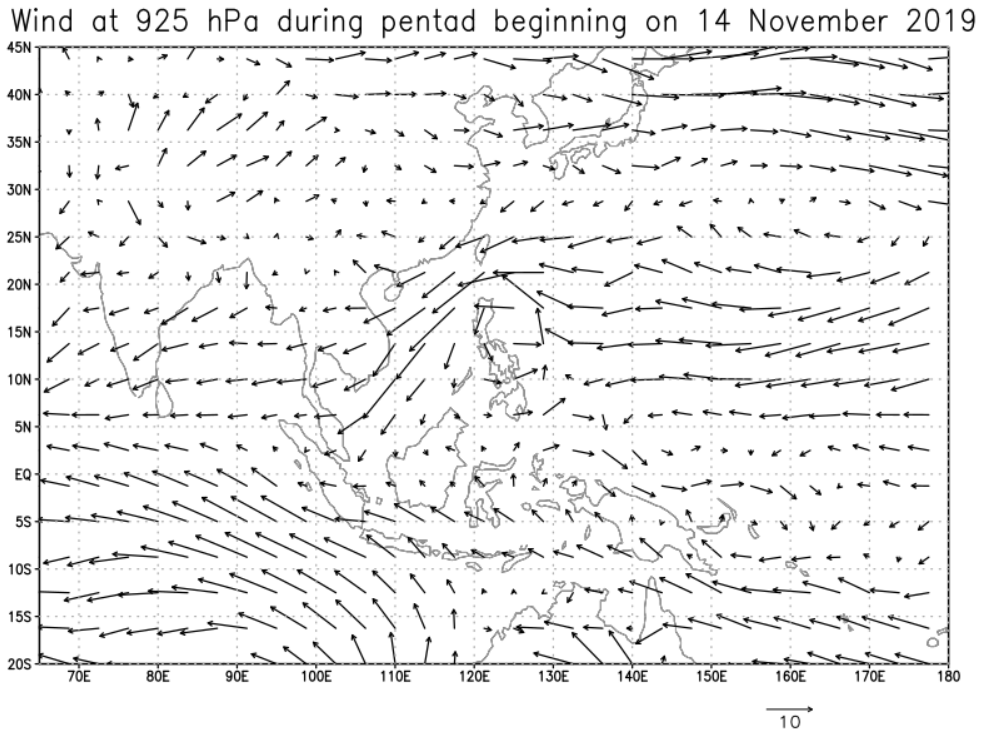

Figure 3: Onset date of NEM 2019/2020

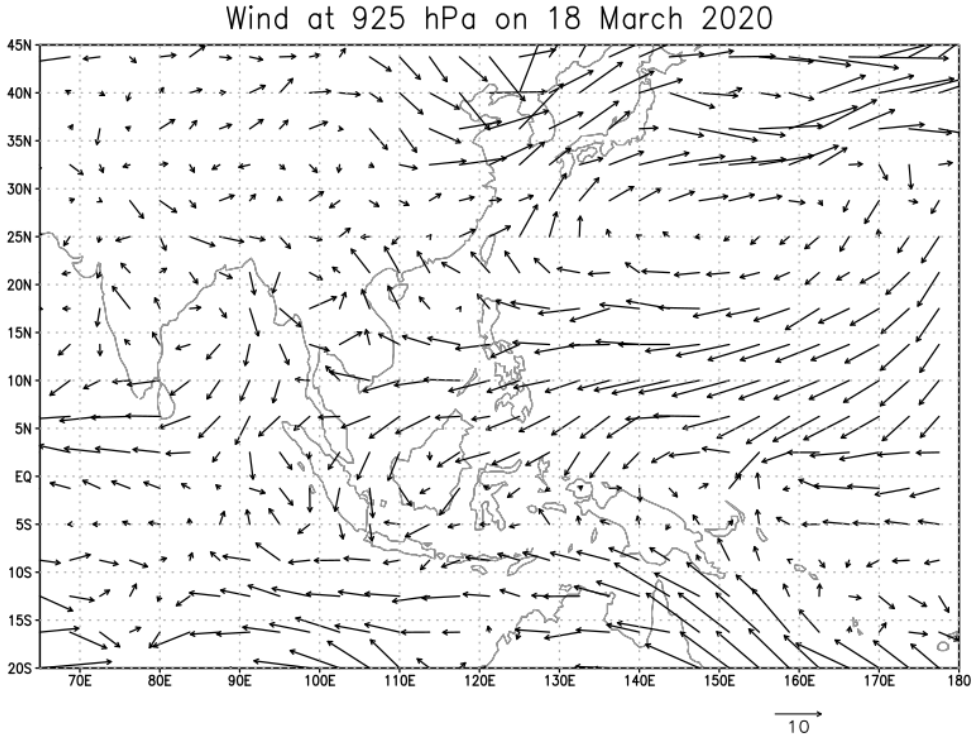

Figure 4: Withdrawal date of NEM 2019/2020

From the synoptic low-level wind analysis, the onset date of NEM 2019/2020 was determined when Malaysia was dominated by the northeasterly wind from Central Asia on the November 13 onwards. The withdrawal date of NEM 2019/2020 was due to the NE wind weakening around the Taiwan region. This is supported by weakening of northerly winds in Kota Bharu from March 18, 2020 followed by weakening of easterly winds at the same period as depicted by the Hovmoller diagram in **Figure 5**. Therefore, the withdrawal date of NEM 2019/2020 was decided on 18 March 2020.

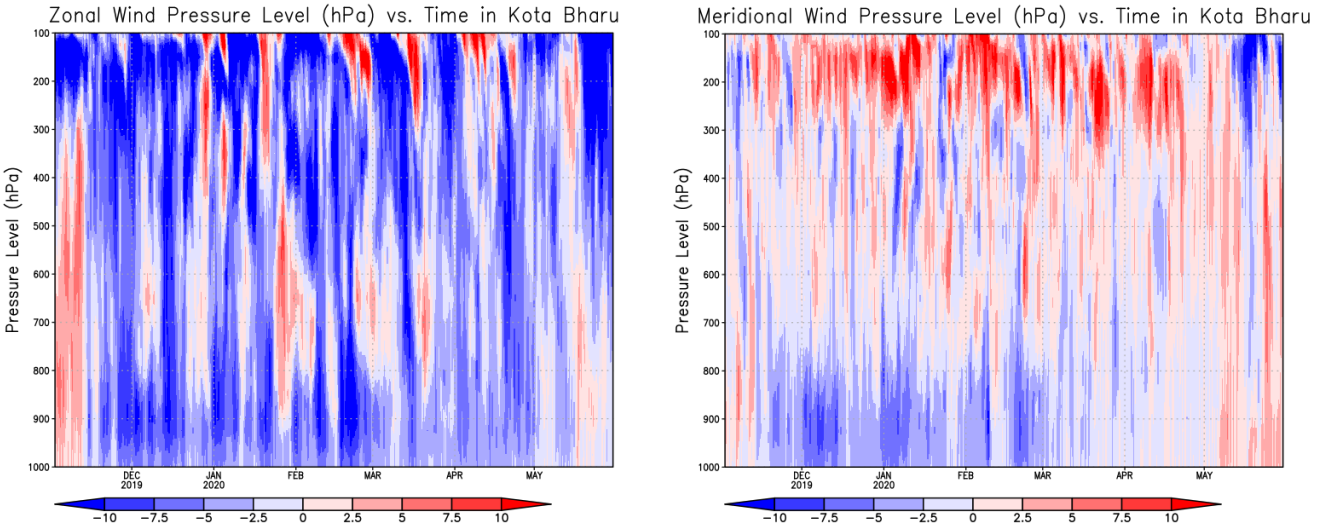

Figure 5: NEMI calculated using the upper air observation over Kota Bharu Station

3.2 Monsoon Surges of the NEM 2019/2020

The date and period of monsoon surges were calculated using MESI and a total of 11 surges were observed during NEM 2019/2020. Based on the definition of a surge by Fakaruddin et al. (2019), the minimum duration of a surge was three days for both meridional surge (MS) and easterly surge (ES) while the minimum duration of the mixed surge (MES) was two days. This NEM 2019/2020 experienced 3 MS, 7 ES and 1 MES, as shown in the MESI time series plotted in Figure 6**.** The highest surge duration was 14 days, which was seen in surge 7 (ES). Meanwhile, the lowest surge duration was three days in the surge 5(MES) and surge 11 (ES). The total of surges during NEM season and NEM 2019/2020 is illustrated in **Table 1**.

Table 1: The total surges during NEM season and NEM 2019/2020

	Climatology	NEM 2019/2020
Total number of surges	29	11
Total surge days	76	71

Overall, the NEM in the Malaysia region continued to prevail in January until February, and gradually weakened in March. However, during NEM 2019/2020 a below-average rainfall in Malaysia was observed. The rainfall distribution for December, January, and February (DJF) is depicted in Figure 7.

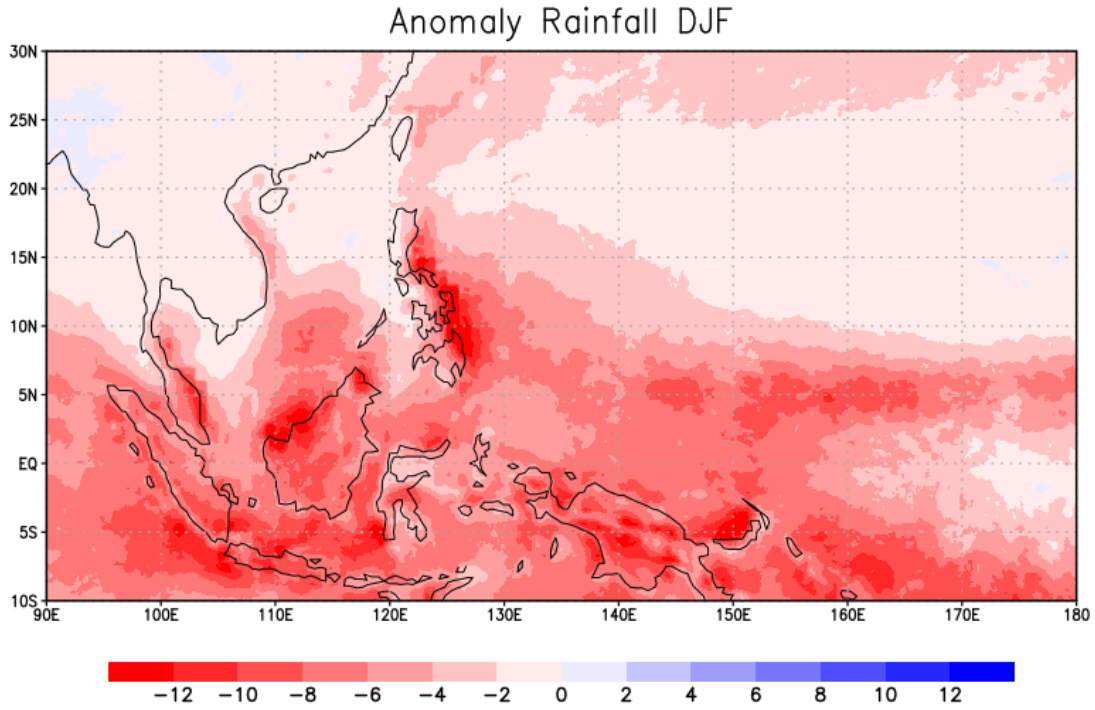

Figure 7: Anomaly average rainfall for DJF for NEM 2019/2020

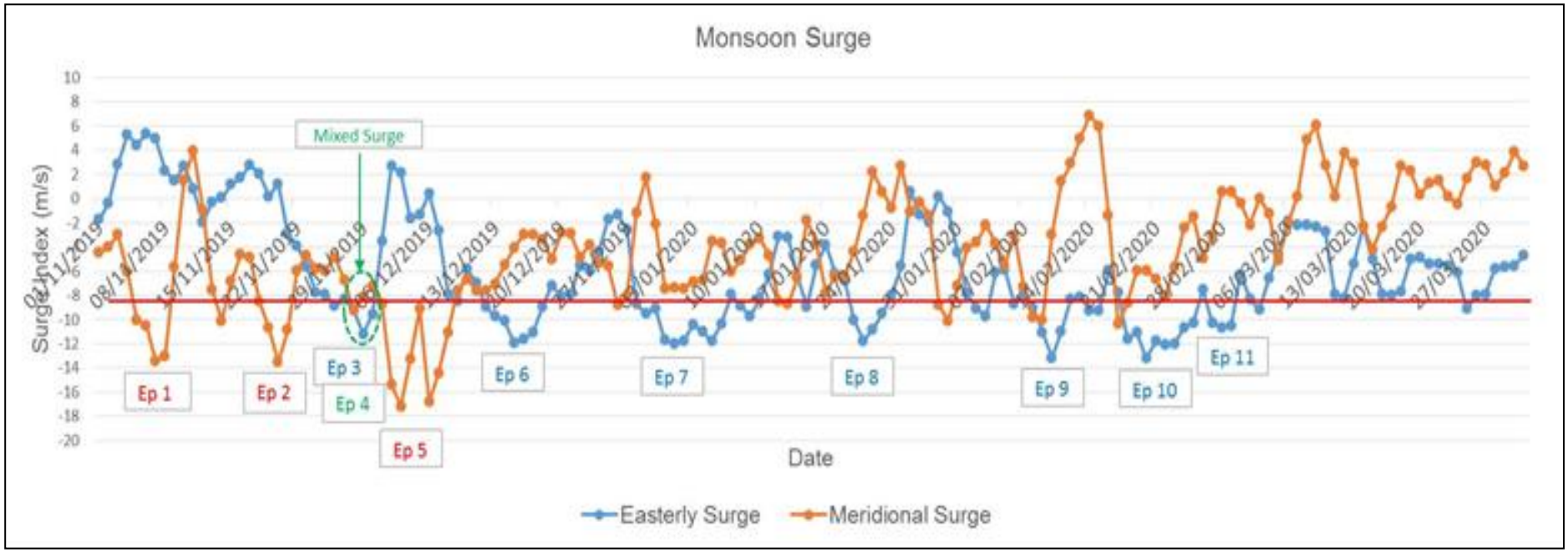

Figure 6: MS, ES and MIXED surge time series plot

3.3 Tropical Cyclone (TC) Occurrence during NEM 2019/2020

Tropical cyclone (TC) has a strong influence on the regional wind and weather patterns even though Malaysia is not directly on the path of cyclones (Munirah et al., 2009). The presence of TC in WNP or SCS can alter the synoptic circulation patterns and also impact the weather over the Asian monsoon region which largely depended on the stage of the TC intensity and the location (Munirah et al., 2009). Climatologically, an average of 27 cyclones per year was observed in the western North Pacific and South China Sea based on 52-year statistics from 1967 to 2019. The most active TC developed between July to October whereby August recorded the highest number of TC. The least number of TC development is seen between the month of January to April of which the lowest TC observed is in the month of February (Munirah et al., 2009). The strongest TC of the year was Typhoon Halong with the maximum wind recorded at 115 knots. The total number of TC occurring through this NEM season were seven, which are listed in Table 2.

Table 2: List of TC during NEM 2019/2020 that has an impact on the weather patterns in Malaysia

No.	Name of TC	Date of TC
1.	Halong	2 - 9 November 2019
2.	Nakri	5 - 11 November 2019
3.	Fengshen	12 - 17 November 2019
4.	Kalmaegi	14 - 20 November 2019
5.	Fungwong	20 - 22 November 2019
6.	Kammuri	26 November - 6 December 2019
7.	Phanfone	22 December - 28 December 2019

3.4 Episode of Surges during NEM 2019/2020

3.4.1 Episode 1: 5 November - 8 November 2019

The first episode of surge for the season occurred from 5-8 November 2019 which was identified as MS. The duration of the surge was 4 days**. Figure 8** shows the large-scale circulation before, during and after the first episode of the surge. The Siberian High (SH) intensified during this period, from 1020 hPa to 1035 hPa, a few days prior to the surge towards the South China Sea (SCS). In the equatorial region,

three cyclonic vortices were observed and embedded in the monsoon trough which was located within 10ºN to 15°N extending from 100°E to 160°E. Typhoon Halong formed in the western Pacific while another two vortices were located in the southern South China Sea (SCS).

One of the vortices in the SCS later migrated northwestward towards Bay of Bengal (BoB) while another remained quasi-stationary in the SCS. Due to the presence of the cyclonic vortex in the offshore Vietnam, the wind patterns in the Malaysian region had been dominated by the southwesterly wind. The southwesterly wind in Malaysia had refreshed as the cyclonic vortex strengthened. During this period, the rain bands were observed mainly in the vicinity of the cyclonic vortices. As reported by Yokoi and Matsumoto (2008), the presence of a vortex in northern SCS could prevent the cold surge from propagating farther southward. As a consequence, the southerly winds from the cyclonic vortex interacted with the northeasterly winds from the MS and formed a strong low-level convergence. Therefore, during this MS period, the rain bands were observed mainly in the vicinity of the cyclonic vortex located off the coast of Vietnam.

During the onset of the cold surge, the cyclonic vortex located in the southern South China Sea (SCS) intensified into the typhoon named Nakri. The monsoon trough in the Northern Hemisphere was observed within 10°N to 15°N and extended from 100°E to 160°E. The presence of Typhoon Nakri remains quasi-stationary throughout the surge period whereby it intercepted the northeasterlies and prevented the intrusion of northeasterlies equatorward. Its presence modified the low-level wind circulation near the equator. During this period, low-level southerlies dominated Malaysia. Therefore, a no-heavy rainfall episode occurred in Malaysia throughout this period. The MS ended on November 9, 2019 while Typhoon Nakri was weakened and finally dissipated by November 11, 2019. The low-level westerly wind still dominated Malaysia.

Two vortices which were located at the west of Philippines (110°E to 120°E) and west of the Pacific Ocean (150°E to 160°E) were weakened, the day after the first surge occurred. The two cyclonic vortices which were referred to as a typhoon were not significant over the Malaysian region. The monsoon trough remained in the same position within 10°N to 15°N.

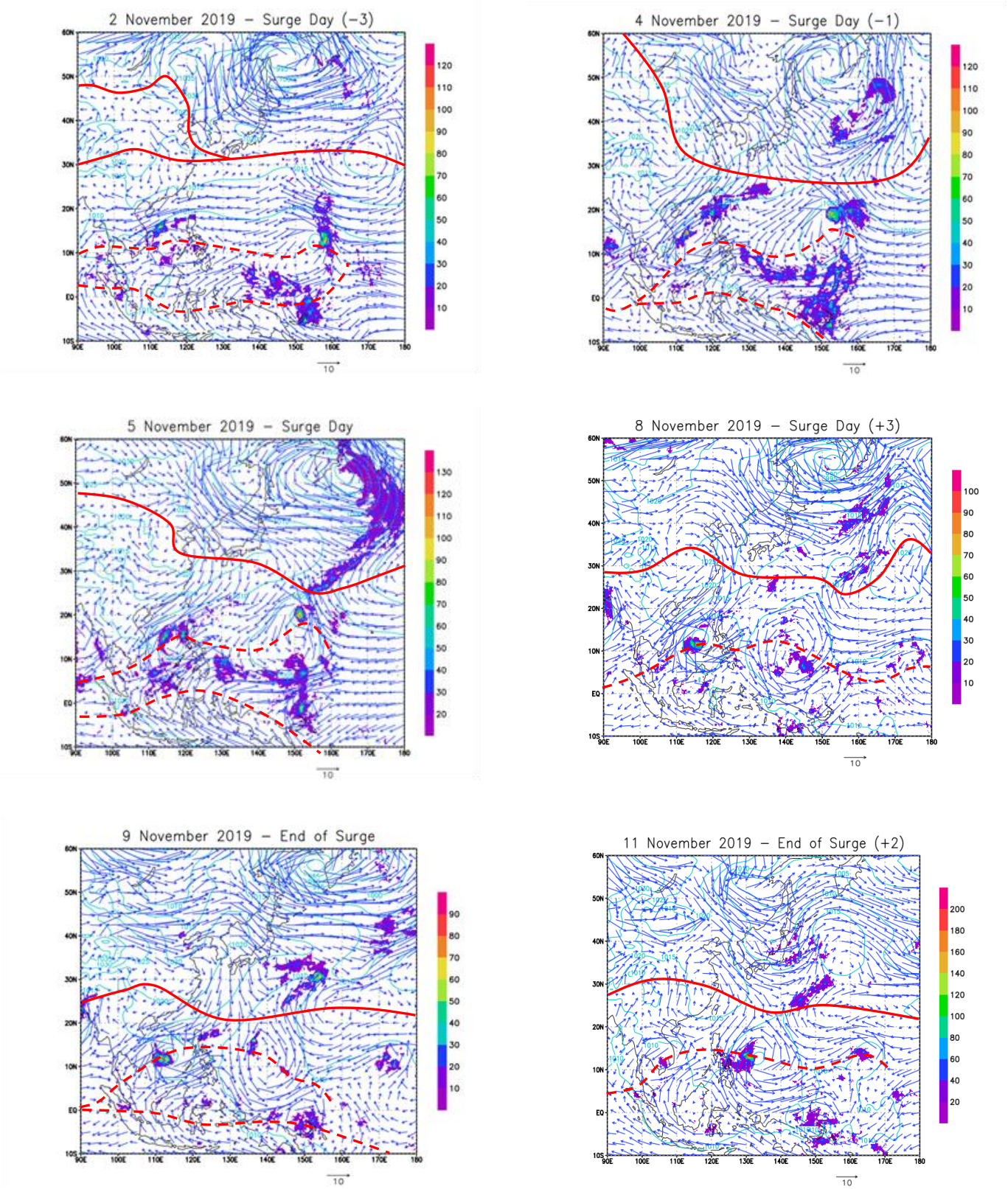

Figure 8: Before, during, and after first surge (5 - 8 November 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.2 Episode 2: 18 - 21 November 2019

Figure 9 shows the large-scale circulation before, during, and after second episode of a surge occurrence. The duration of episode 2 was four days and classified as MS**.** A cyclonic vortex was observed to have shifted from north of Japan to the north of the Pacific Ocean within 40°N to 60°N and extending from 130°E to 180°E starting on 15 to 17 November 2019. The subtropical ridge in the Northern Hemisphere was consistently observed within 20°N to 40°N and extended from 90°E to 160°E. Typhoon Kalmaegi had developed and moved slowly from the west to the northwest towards Babuyan Islands, north of Luzon, Philippines. Then, the system gradually weakened as it moved towards SCS.

The broad easterly wind from the western Pacific Ocean penetrated into the South China Sea with a magnitude of 10 to 20 knots. The subtropical ridge extended from the western Pacific Ocean to mainland Asia between 30°N to 35°N extending from 100°E to 170°E. The near equatorial trough was slightly observed over the western Pacific Ocean but did not extend over the Peninsula Malaysia. Low-level easterlies winds dominated the Peninsula Malaysia and the wind convergence was observed between southern Borneo and southern Peninsular Malaysia during this episode. However, southern Johore and Sarawak recorded slightly below average during this surge.

The synoptic wind analysis day 22 and 24 of November 2019 after surge 2 was also observed. The subtropical ridge was observed between 30°N to 40°N, extending from 100°E to 180°E at the end of this surge episode. The wind speed decreased from 5 to 10 knots over the Malaysian region after the surge.

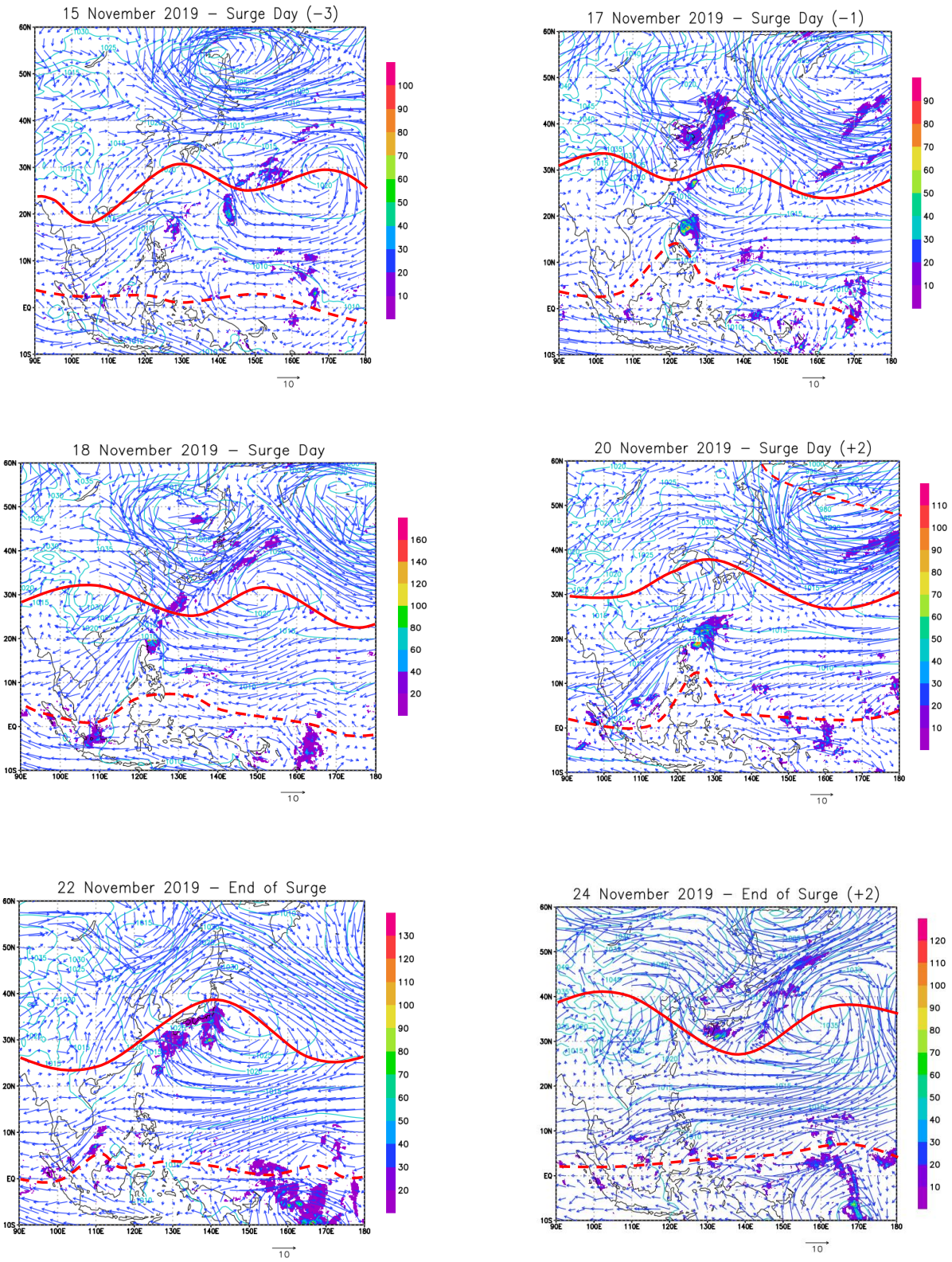

Figure 9: Before, during, and after second surge (18 - 21 November 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.3 Episode 3: 26 - 30 November 2019

The large-scale circulations before, during, and after third episode of surge are shown in **Figure 10**. The northeasterly wind from the Western Pacific Ocean penetrated the Malaysian Region and was observed to have a magnitude of 10 to 20 knots. The near equatorial trough was located between 0°N to 5°N and 100°E to 180°E. No heavy rainfall was recorded prior to the surge 3.

The third surge occurred from 26 until 30 November 2019 which was identified as ES. The duration of the ES was five days**.** The cyclonic vortex slightly moving toward the east of Peninsula Malaysia from the western Pacific Ocean between10°N to 20°N and 160°E to 140°E. The monsoon trough was present over the western Pacific Ocean and SCS. The tracking of Typhoon Kammuri showed that it moved westward from 160°E to 110°E and between 10°N to 20°N from 26 November 2019 to 6 December 2019. The impact of Typhoon Kammuri is not clearly observed as it was located far from the Malaysian region. The rainfall amount increased in Kelantan compared to other states in the east coast of Peninsula Malaysia throughout the third surge episode. The meteorological station recorded rainfall at 105.23mm (Kota Bharu) and 106.2mm (Kuala Krai), respectively, which was the highest logged rainfall.

The day after third episode of surge started from 1 to 3 December 2019. During this period, Typhoon Kammuri moved from WNP and crossed the Philippines. There was another cyclonic circulation observed between 5°N to 10°N and 140°E to 150°E. The wind convergence in the area of Bunguran (between the Peninsula Malaysia and Kuching) was observed.

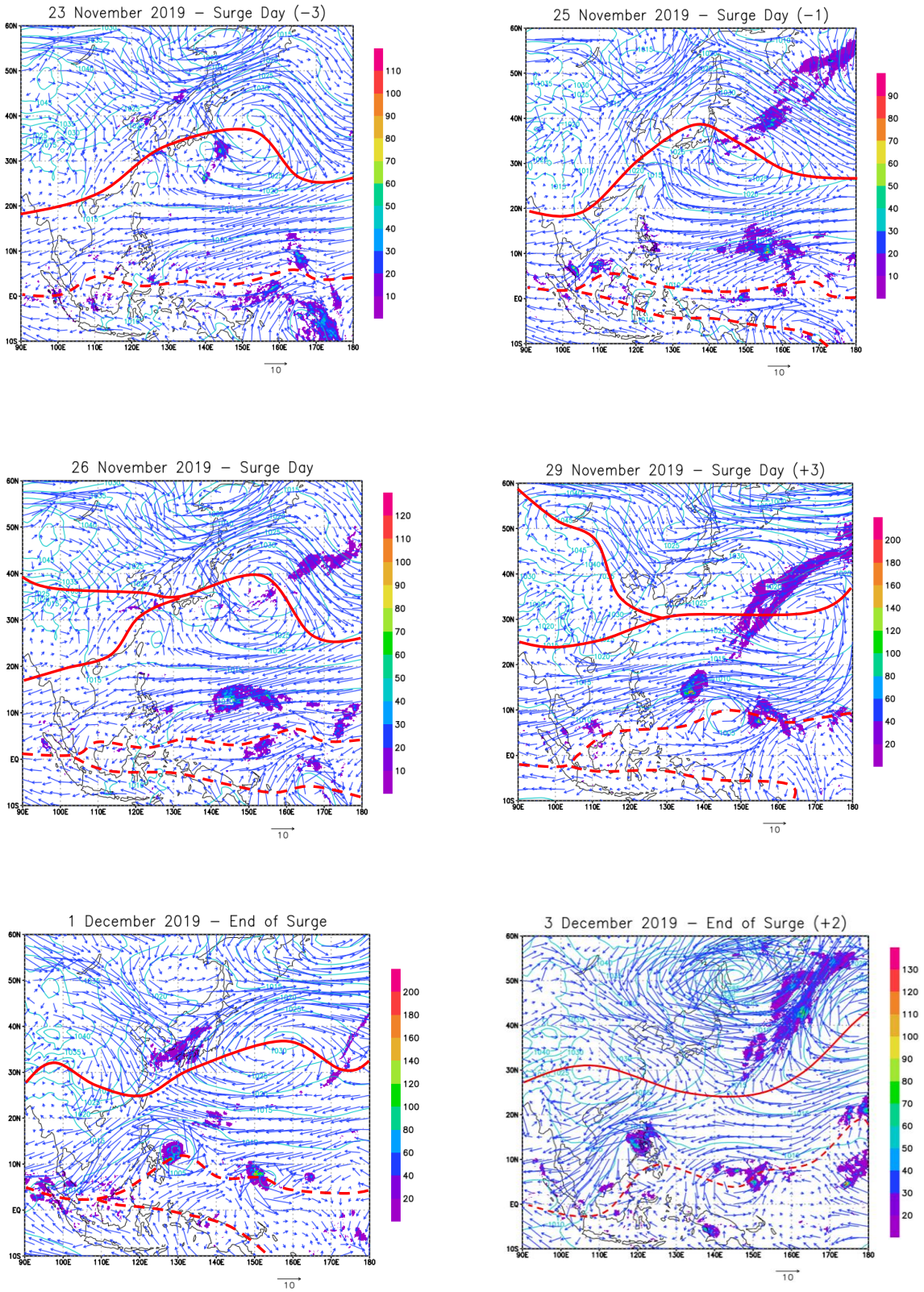

Figure 10: Before, during, and after Surge 3 (26 - 30 November 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.4 Episode 4: 28 November - 8 December 2019

Figure 11 shows the large-scale circulation before, during, and after fourth episode of surge. The wind flowed from northern South China Sea and crossed the equatorial southeasterly from Java which then converged between 0°N to 5°N and 100°E to 110°E along the monsoon trough in the east coast of Peninsula Malaysia.

The fourth surge episode started from 28 November to 8 December 2019. This surge was classified as meridional surge with a recorded duration of 11 days**.** The 15 to 20 knots northeasterly wind dominated over the Malay Peninsula during this period. A cyclonic circulation that was observed between 0°N to 7°N had shifted westward from western North Pacific between 150°E to 120°E. This surge intensified the northeasterly winds over the SCS and directly flowed to the east coast of Peninsula Malaysia which impacted Kelantan and Terengganu. The heaviest rainfall during this surge episode was recorded on the December 1, 2019 in Gong Kedah, Terengganu meteorological station (366.8mm).

The end of the fourth surge was observed on 9 to 11 December 2019. Northeasterly wind speed decreased as compared to the surges from 15 - 20 knots to 10 - 15knots. The monsoon trough was located around 0°N to 5°N, which maintained the same position two days prior to the fourth surge episode. Additionally, the broad northeasterly from mainland Asia converged in Borneo. This convergence had enhanced the convection over areas in Sarawak.

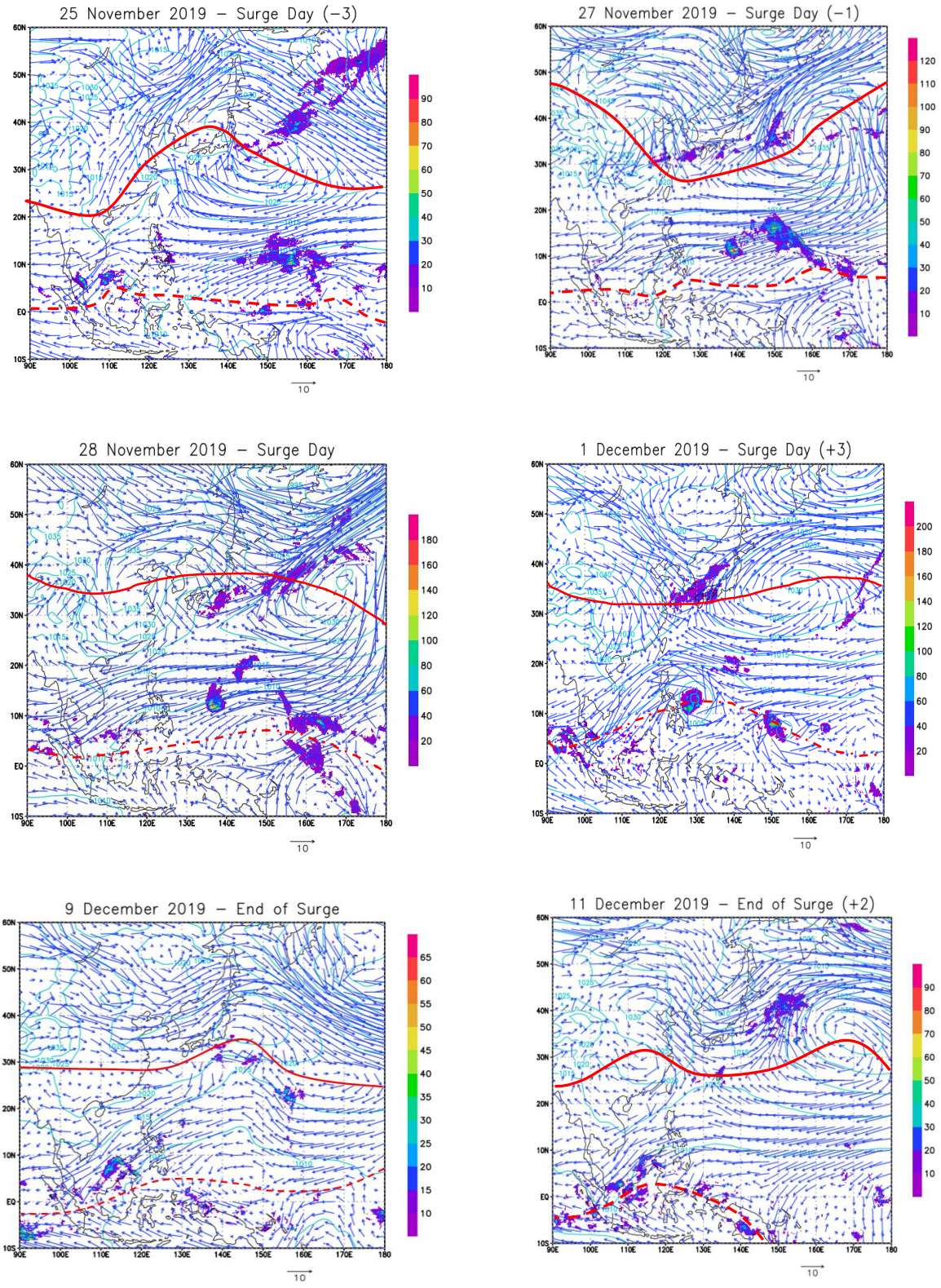

Figure 11: Before, during, and after Fourth Surge (28 November - 8 December 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.5 Episode 5: 28 - 30 November 2019

Figure 12 shows the large-scale circulation before, during, and after fifth episode of surge. In November, the monsoon trough had migrated to the south between 3°N to 5°N which was zonally positioned west of Borneo logging the same climatological position. The northeasterly wind had dominated over Malaysia.

A mixture of both easterly surge and meridional surge was identified as Mixed Surge (MES) with a duration of three days. During the surge, the cyclonic circulation was observed in the western Pacific Ocean which slightly moved towards east of the Philippines. The strong northerlies from mainland Asia and the northern Pacific Ocean gathered broad easterlies from the western Pacific whereby moisture was brought in directly to the Malaysian region, especially in Kelantan and Pahang. The wind speed was present between 10 to 20 knots during the surge 5.

At the end of this MES on 1 to 3 December 2019, the meridional component of MES disappeared but the easterly component still remained and continued until 8 December 2019 as part of the surge 4 (ES). Meanwhile, after the surge 5, the cyclonic circulation passed through the Philippines and moved in the northern SCS, which was referred to as Typhoon Kammuri. The heavy rainfall occurred on 1 December 2019 which was linked to the surge 4 event.

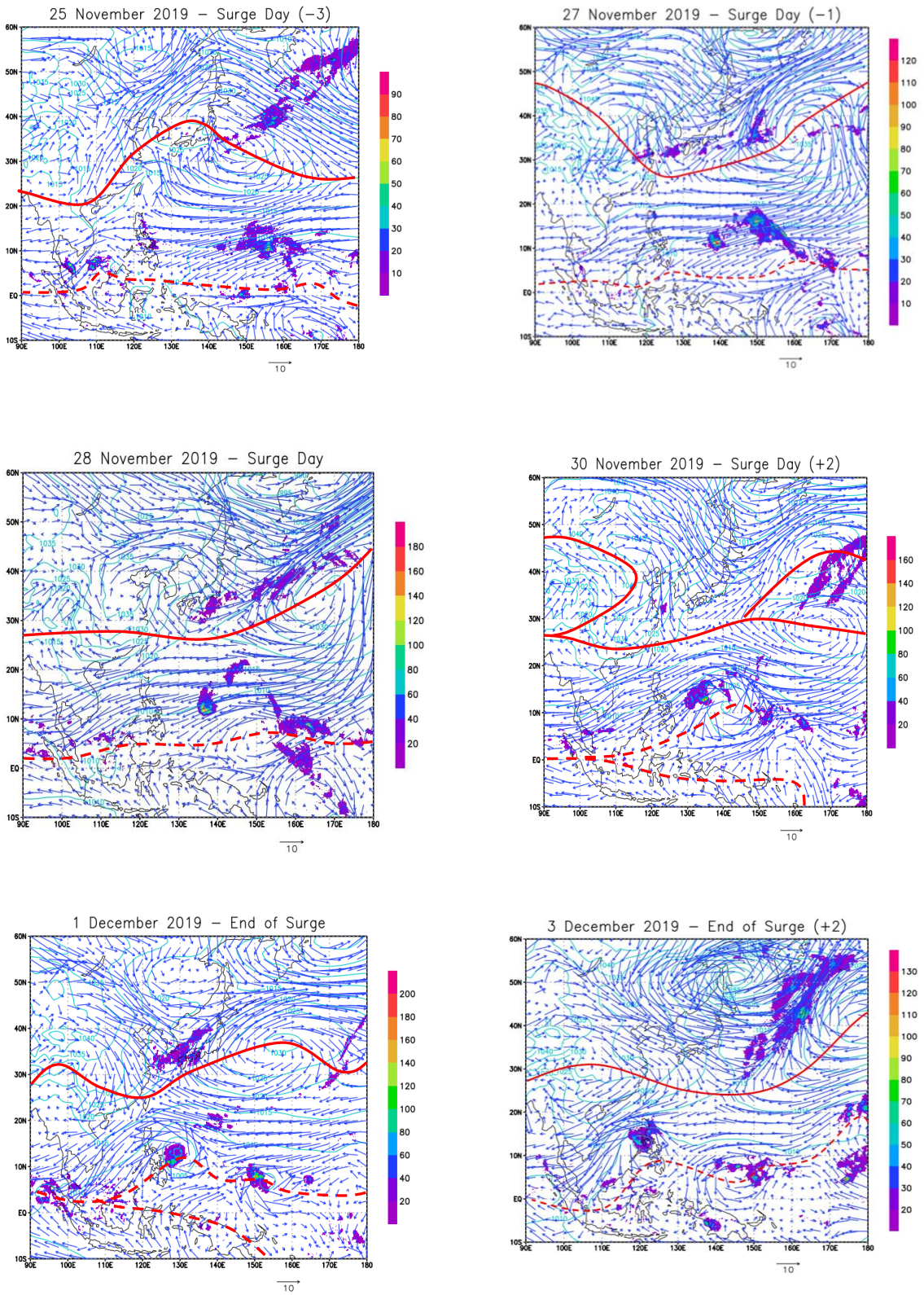

Figure 12: Before, during, and after fifth Surge (28 - 30 November 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.6 Episode 6: 12 - 20 December 2019

The sixth episode of the season occurred from 12th to 20th December 2019 for nine days which was identified as ES. **Figure 13** shows the large-scale circulation two days prior to the ES. Double near equatorial trough was observed between 0°N to 5°N for the northern trough and 0°S to 5°S for the southern trough which was consistent with the climatological position. A cyclonic circulation was observed in southern Borneo within the monsoon trough. Meanwhile, both troughs extended from the western Pacific Ocean until the equatorial Indian Ocean and merged at south of Sumatra.

This sixth surge coincided with a heavy rainfall episode over Johore and Pahang, whereby a maximum rainfall was recorded over southern Pahang followed by southern Johore based on the rainfall meteorological station. The strong easterly wind reported a speed of 10 knots to 20 knots from the western Pacific Ocean penetrating into the South China Sea. On 12 December 2019, the cross-equatorial flow had diverted moisture away from Peninsula Malaysia to the Southern Hemisphere leading to enhanced convection in Sumatra and Java. But on 14 December 2019, the moisture was diverted to the southern Peninsula Malaysia located in Johore and Pahang whereby the monsoon trough had shifted slightly northward from 5°S to the near equator. The accumulated rainfall exceeded 100mm (per day) in Johore and Pahang rainfall stations.

Synoptic wind patterns at the end of the sixth surge was plotted between 21 December to 23 December 2019. A cyclonic circulation was propagated from the western Pacific Ocean to the northeast of Philippines. Northern Sabah notably received above-average amounts of rainfall when the cyclone was located at southern Philippines.

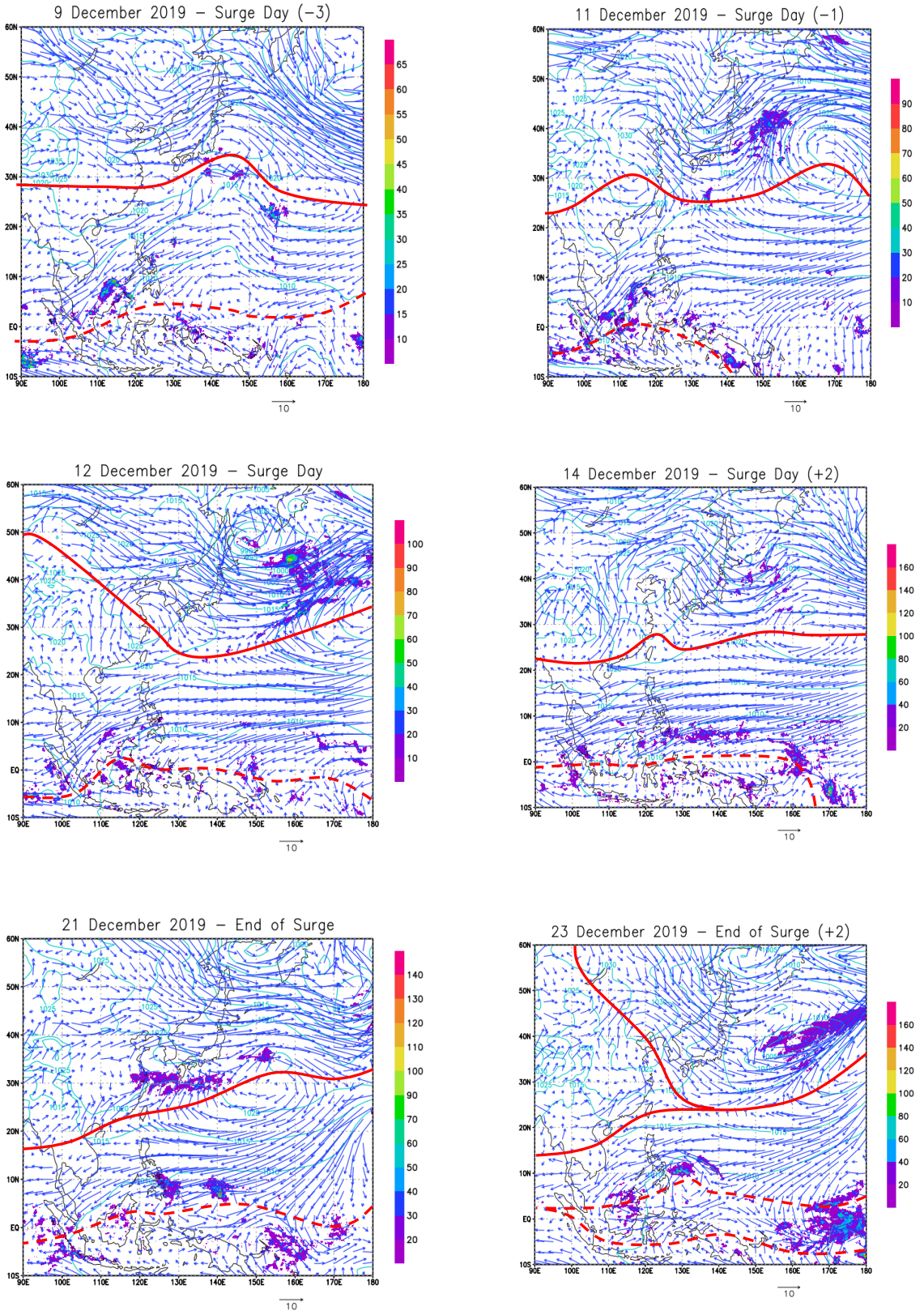

Figure 13: Before, during, and after sixth Surge (12 - 20 December 2019)

**Color legend refers to precipitation amount (mm/day)*

3.4.7 Episode 7: 28 December - 10 January 2020

The seventh episode of the surge for this NEM season occurred from 28 December 2019 to 10 January 2020 which was identified as ES. This ES had recorded the longest surge period of 14 days. The synoptic wind pattern two days prior to the surge is shown in **Figure 14**. A cyclonic circulation was located within 125°E to 130°E in central Philippines. The northeasterlies had strengthened on 28 December 2019 until the end of this surge period.

The strong northeasterlies from the WNP Ocean was diffluent towards the equator and southern SCS. Most of the monsoon outburst from Siberia High was absorbed by the strong low-pressure system located over the western Pacific Ocean between 38°N and 175°E. As a result, the strong north westerlies split into two branches which went into the low-pressure system while the other components joined the eastern flanks of the subtropical high (STH) which turned to strong easterlies in the Malaysian region. It was observed that the STH in the NWP was pushed equatorward due to the Siberian High outbreak. The ES that had propagated to the South China Sea flew into the near-equatorial trough across southern Borneo. Maximum rainfall was recorded on 30 December 2019 with a logging of 210.6mm per day from Bintulu rainfall stations during this period.

At the end of the ES, a cyclonic vortex which was known as Borneo Vortex (BV) was clearly formed on the 11 January 2020**.** The BV contributed to the wet conditions over the coastal regions of Sabah and Sarawak. The BV had dissipated by 13 January 2020 due to the conditions of BV that did not indicate strong counter clock wise circulation and high vorticity values (Paulus and Shanas, 2017).

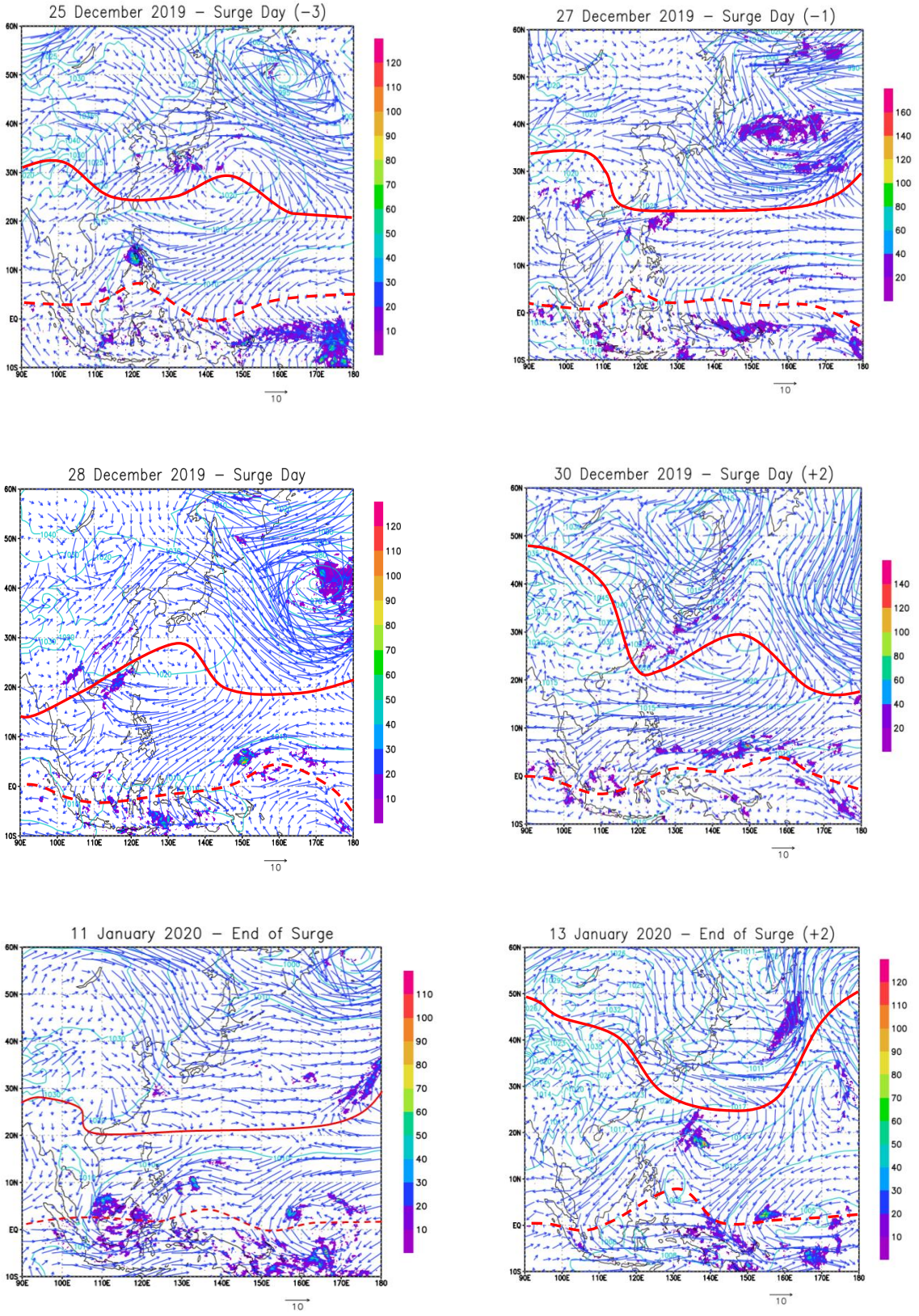

Figure 14: Before, during, and after seventh surge (28 December -10 January 2020)

**Color legend refers to precipitation amount (mm/day)*

3.4.8 Episode 8: 20 - 23 January 2020

The eighth episode of surge occurred from 20 to 23 January 2020 for four days which was identified as ES. The synoptic wind pattern prior to the ES onset on 17 to 18 January 2020 was plotted as in **Figure 15**. The monsoon trough was exhibited from the WNP ocean until the Malay Peninsula within 0°N to 5°N and 110°E to 170°E. The BV was also observed on 17 to 18 January 2020 with its centre mostly over the land of West Borneo.

An axis of meridional trough along the coast of East Asia was observed before the outburst of the Siberian High. Due to the low pressure, the Siberia High branched out into two with zonally and equatorward movements. The westerly zonal wind moving from the SH then turned along the eastern flank of the subtropical high as easterly winds in the Pacific became strong easterly flows as it entered Malaysia. Additionally, there was a strong cyclonic shear of the northeasterlies wind off the coast of Borneo. A cross equatorial flow created wind divergence over the east coast of the Peninsula Malaysia and it diverted most of the moisture away from Malaysia to the Southern Hemisphere leading to enhanced convection in Sumatra and Java. There were no significant heavy rainfall occurrences observed over Malaysia during this ES episode.

The easterly wind flow dominated over Malaysia from 24 January 2020. On 26 January 2020, the wind flow from the western Pacific Ocean diverged to Indochina. The anticyclonic located between the equator and 30°N extended from 110°E to 180°E had originated from southeastern coast of China and was part of the southward movement of another branch of SH. It later shifted northeastward and strengthened as the low-pressure belt along the coast of East Asia shifted eastwards. Light and variable winds dominated Malaysia on 26 January 2020.

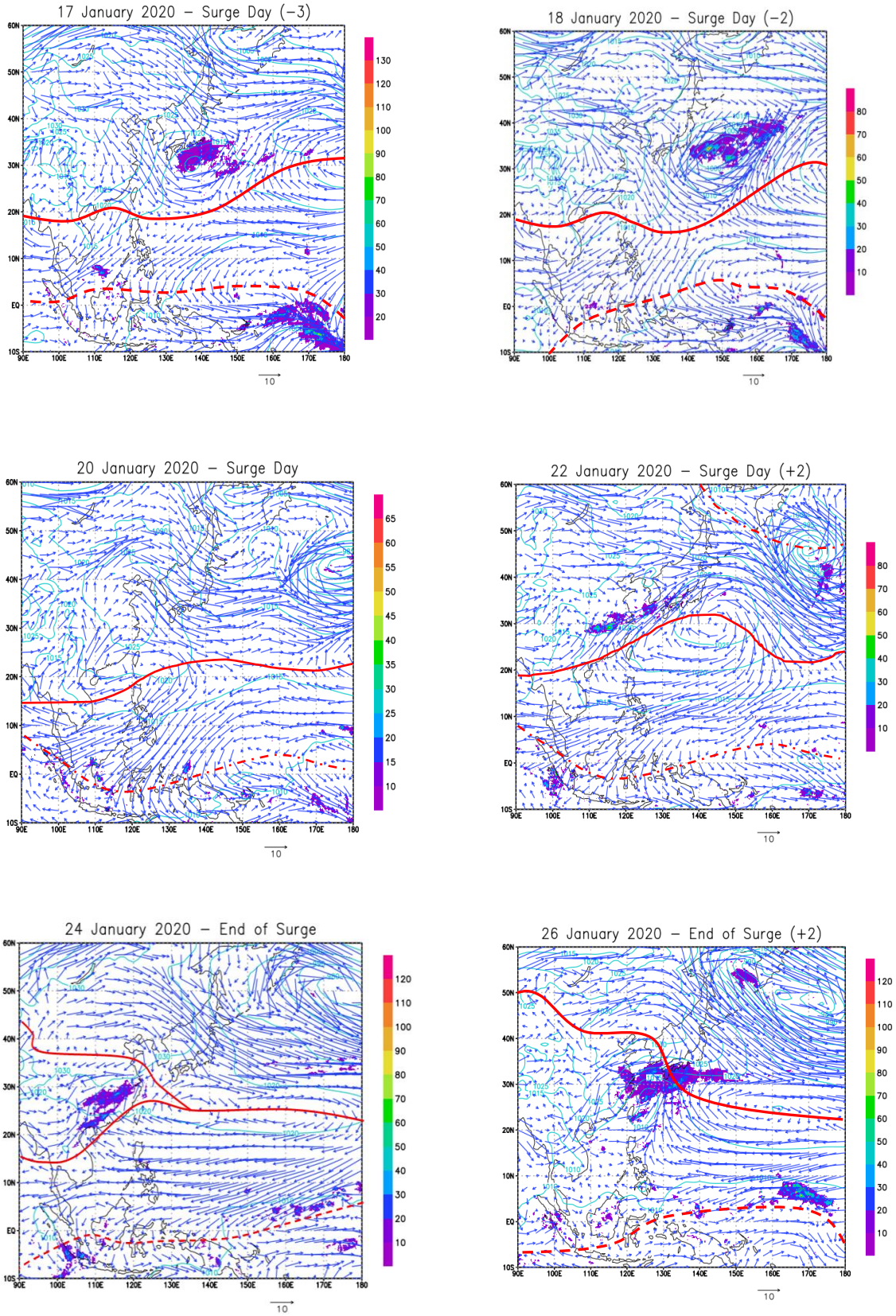

Figure 15: Before, during, and after Eighth Surge (20 - 23 January 2020)

**Color legend refers to precipitation amount (mm/day)*

3.4.9 Episode 9: 6 - 15 February 2020

Circulation in the lower troposphere is depicted in **Figure 16** which clearly shows the near equatorial trough located between 5ºN to 5°S and 100°E to 180°E consistent with the climatology position. In February, the monsoon trough was located along the equator while the subtropical ridge was observed along 20°N to 30°N and 100°E to 160°E. Both synoptic features were located in their southernmost position.

The ninth episode of the surge occurred from 6 to 15 February 2020 which was identified as ES with a 10-day duration. A strong cross-equatorial flow was observed throughout ES, whereby the Southern Hemisphere trough had maintained its position within 0°N and 5°S. It had also extended from 100°E to 180°E which was consistent with long term average conditions. Overall, in February 2020, the southern part of Peninsula Malaysia and the western part of Sarawak still received above average amounts of rainfall similar to the mean climatological rainfall data from the year 1946 until 2014 (Fadila et al., 2016).

During the post-surge episode, the monsoon trough had maintained a position between 0°N and 5°N and extended from 100°E to 180° E. The presence of BV over west of Sarawak caused the diffluence of wind over Johore and the rainfall was observed over the west of Sarawak. The day after surge 9, the strong cross equatorial flow diverged to the SH trough and caused rainfall to become more diverged into southern Borneo and west of Sumatra.

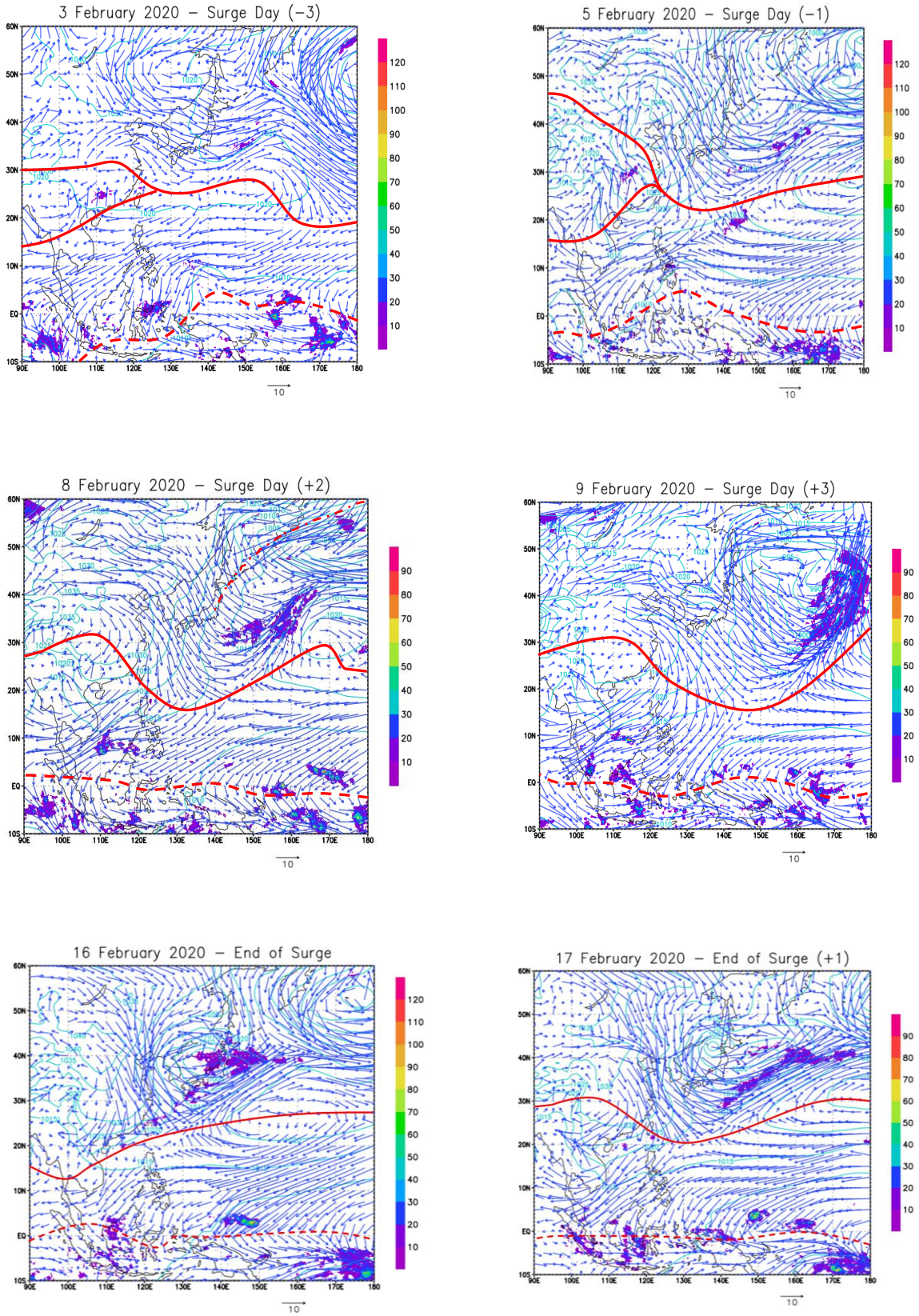

Figure 16: Before, during, and after Ninth Surge (6 -15 February 2020)

**Color legend refers to precipitation amount (mm/day)*

3.4.10 Episode 10: 18 - 25 February 2020

The tenth identified surge of this NEM had reported eight days of ES started from 18 to 25 February 2020 as depicted in **Figure 17**. There was a distinct speed divergence in the whole SCS between 15 to 17 February 2020.

The wind broad easterlies from the western Pacific were dominated over Malaysia during the ES episode. The monsoon trough extended from the western Pacific Ocean to the southern South China Sea between 5°N to 5°S and 100°E to 180°E. During this tenth surge there was no significant heavy rainfall occurrence associated with the ES. This cloud was due to the cross equatorial that had dominated the near equatorial flow which then flew into the Southern Hemisphere of the southward shifted monsoon trough.

Synoptic wind patterns were observed during the two days after this ES. In general, relatively clear weather still persisted. The monsoon trough had shifted northward between 0°N to 5°N and 100°E to 180°E as compared to its mean position in January.

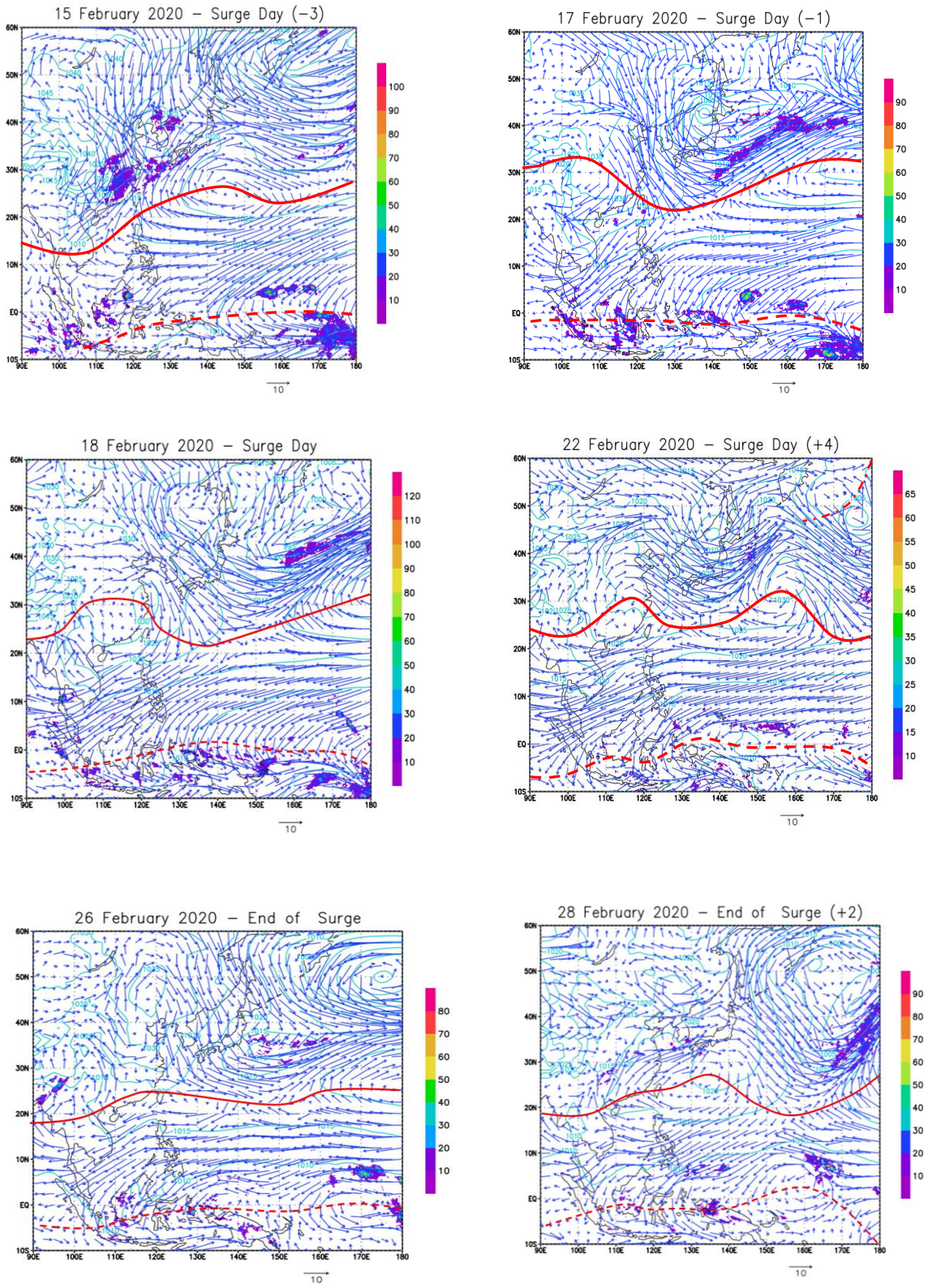

Figure 17: Before, during, and after Tenth Surge (18 - 25 February 2020)

**Color legend refers to precipitation amount (mm/day)*

3.4.11 Episode 11: 27 - 29 February 2020

The last surge episode for the season 2019/2020 started from 27 to 29 February 2020 which was identified as easterly surge depicted in **Figure 18**. The lowest day duration of the surge was three days as compared to all episodes in the NEM season 2019/2020. Two days prior to the eleventh surge episode was still categorized as part of the tenth surge. The monsoon trough had maintained the same position as the previous surge. The subtropical ridge was observed between 15°N to 25°N and 100°E to 170°E. The position of the subtropical ridge and the monsoon trough caused the northeasterly wind from the Pacific Ocean to cross the equator into the Southern Hemisphere. Then, the enhanced convection occurred in Java and southern Sumatra but drier conditions were seen in the equatorial SCS.

The eleventh episode of the surge occurred from 27 to 29 February 2020 which was identified as ES with a three-day duration. Drier conditions in the equatorial SCS were observed in the three days of the surges. The persistent cross equatorial flow in February and onwards have led to dry surges in Malaysia.

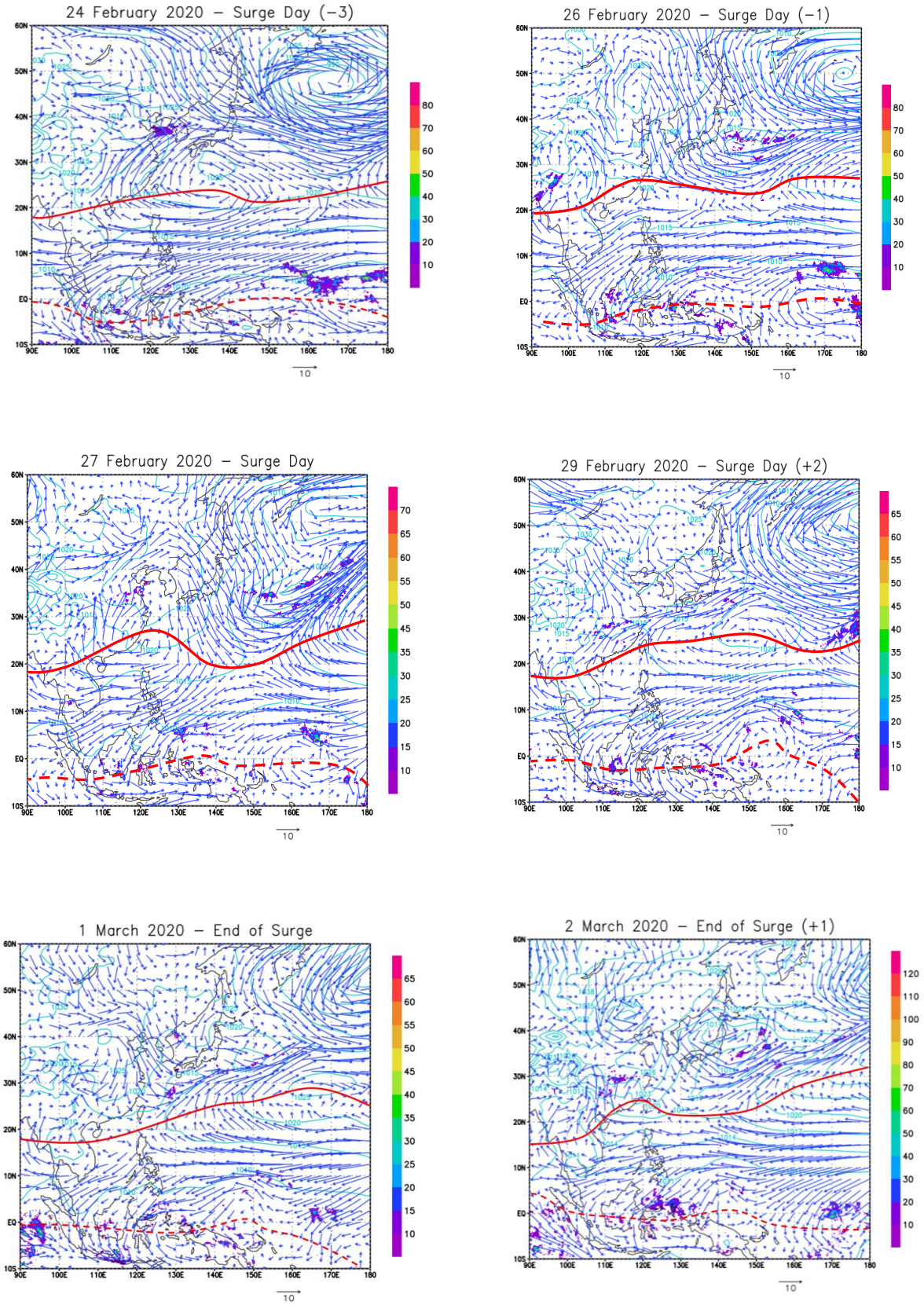

Figure 18: Before, during, and after Eleventh Surge (27 - 29 February 2020)

**Color legend refers to precipitation amount (mm/day)*

3.5 Rainfall Episode during NEM 2019/2020

During NEM 2019/2020, there were 11 episodes of surges was observed including the ES, MS, and MES surge. From these surges, only episodes 4, 6, and 7 of the surges showed the daily accumulated rainfall exceeding 150mm at certain stations, as shown in **Figure 19**. The three heavy rainfall episodes occurred in meridional cold surge (Episode 4) and easterly cold surge (Episodes 6 and 7). Compared to all TC that had occurred during NEM 2019/2020, only TC Kammuri coincided with a heavy rainfall episode (Episode 4) in the northeastern Peninsular Malaysia (28 November to 8 December 2019). The intensity of the TCs was found to increase rainfall probability.

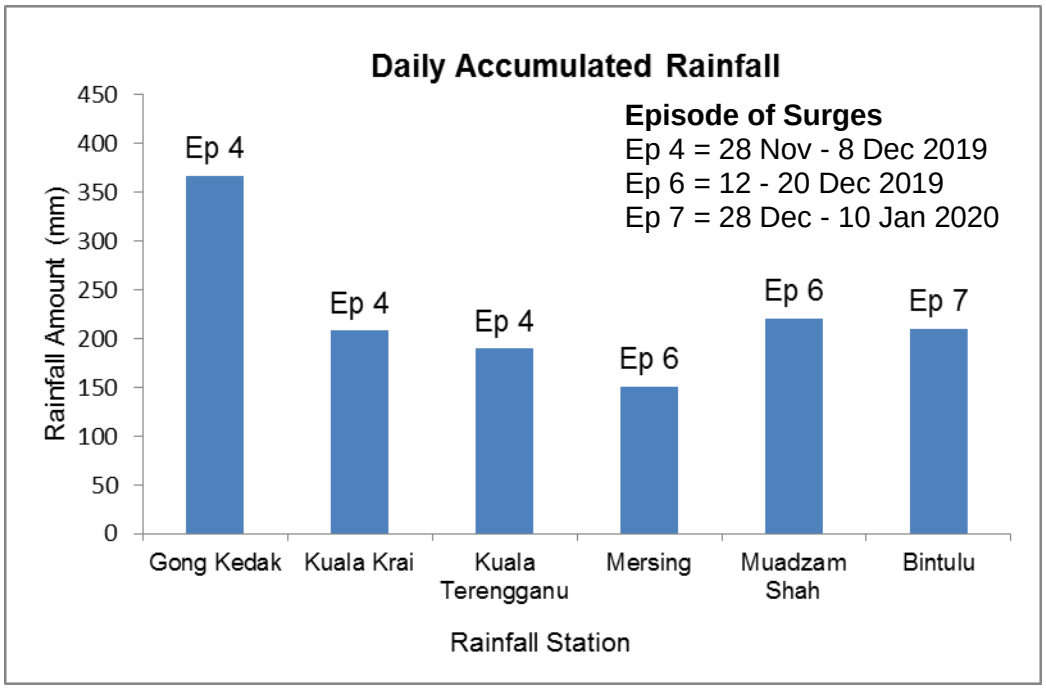

Figure 19: Daily Accumulated Rainfall exceeding 150mm for certain surge episodes

3.6 ENSO, MJO and IOD Variability

3.6.1 El-Niño Southern Oscillation (ENSO)

The Oceanic Niño Index (ONI) was used to identify El Niño (warm-red) and La Niña (cool-blue) events in the tropical Pacific with a running 3-month mean SST anomaly for the Niño 3.4 region. The events are defined with five consecutive overlapping 3-month periods at or above the +0.5° anomaly for warm (El Niño) events and at or below the -0.5° anomaly for cold (La Niña) events. An El Niño event is categorized as weak, moderate, strong and very strong event if the Niño3.4 index ranged between 0.5 to 0.9°C, 1.0 to 1.4°C, 1.5 to 1.9°C or more than 2.0°C, respectively. Likewise, a La Niña event was categorized as weak, moderate, strong and very strong event if Niño3.4 index ranged between −0.9 to −0.5°C, −1.4 to −1.0°C, −1.9 to −1.5°C and less than −2.0°C, respectively (Tangang et al., 2017).

The data of ENSO for 2019 and 2020 is tabulated in Table 3. Based on the table, The El-Niño Southern Oscillation (ENSO) continued to remain in the neutral state where neither El Niño nor La Niña conditions were reported.

Table 3: ONI values showed warm (red), cold (blue) and neutral (black) periods indicated the ENSO episodes.

Month/ Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2019	0.8	0.8	0.8	0.7	0.6	0.5	0.3	0.1	0.1	0.3	0.5	0.5
2020	0.5	0.6	0.5	0.3	0.0	-0.2	-0.4	-0.6	-0.9	-1.2	-1.3	

3.6.2 Madden Julian Oscillation (MJO)

The Madden-Julian Oscillation (MJO) is characterized as an eastward moving pulse of cloud and rainfall near the equator that typically recurs every 30 to 60 days (Wheeler & Hendon, 2004). The MJO phase diagram illustrates the progression of the MJO with 8 different phases that correspond to different locations along the equator as shown in **Figure 20**. The index that falls within the circle (less than 1)

showed that the MJO is considered weak or indiscernible and whatever is outside the circle is considered strong (more than 1). The summary of major MJO starting from November 2019 to March 2020 is shown in Table 4. Broadly, Phases 4 and 5 normally bring wetter conditions over the Maritime Continent including Malaysia (Wheeler et al., 2004). The impact of MJO during NEM monsoon is weakening the cold surges. Therefore, there are 8 MJO events that had occurred in Phase 4 and 5 in which the highest MJO number was 7. But only 3 MJO events had occurred during the cold surge of the NEM monsoon 2019/2020 as shaded in Table 4.

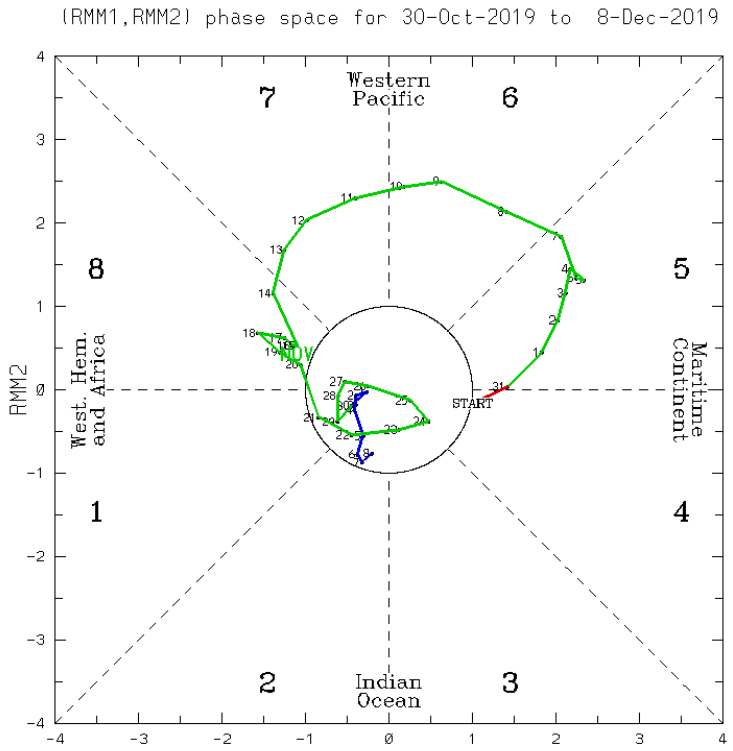

Figure 20: The MJO phase diagram for October (red) - November (green) - December 2019 (blue) (*Source: Bureau of Meteorology*)

Table 4: Major MJO Events during NEM Monsoon 2019/2020

Month	Date	Num of MJO Days	Phase
November	**1 - 7**	**7**	**5**
	8 - 10	**3**	**6**
	11 - 13	3	7
	14 – 20	**7**	**8**
December	12 - 13	2	2
	15	1	3
	24 - 26	3	6
	27 - 29	3	7
	30	1	8
January	6 - 10	5	4
	11 - 14	4	5
	15 - 19	5	6
	20 - 24	5	7
	29 - 30	2	6
February	7 - 10	4	5
	11 - 16	6	6
	17 - 19	2	5
	23 - 24	2	8
March	1 - 2	2	3
	4 - 5	2	4
	6 - 9	4	5
	10 - 11	2	6
	13	1	6
	17 - 18	2	1
	19 - 21	3	2
	22 - 26	5	3
	27 - 31	5	4
Total Num. of MJO Days		**91 days**	

(Shaded date refers to the Cold Surge Events)

3.6.3 Indian Oscillation Dipole (IOD)

Indian Oscillation Dipole (IOD) is defined as the different sea surface temperature anomalies (SSTA) between the western and eastern Indian Ocean. A positive IOD is characterized by warmer than average water in the western Indian Ocean (WIO) and cooler than average water in the eastern Indian Ocean (EIO) and vice versa for negative IOD.

The Indian Ocean Dipole (IOD) is slightly positive but continues to weaken and a return to a neutral state starting in the middle of December 2019 as shown in **Figure 21**. The IOD typically remains in the neutral phase during the season from January to March 2020. The occurrences of El-Nino and the positive IOD phase in the early monsoon resulted in drier than normal conditions (Mahmud, 2018). This condition increased the convection over the Indian Ocean and BOB displaying less moisture over the Malaysian region.

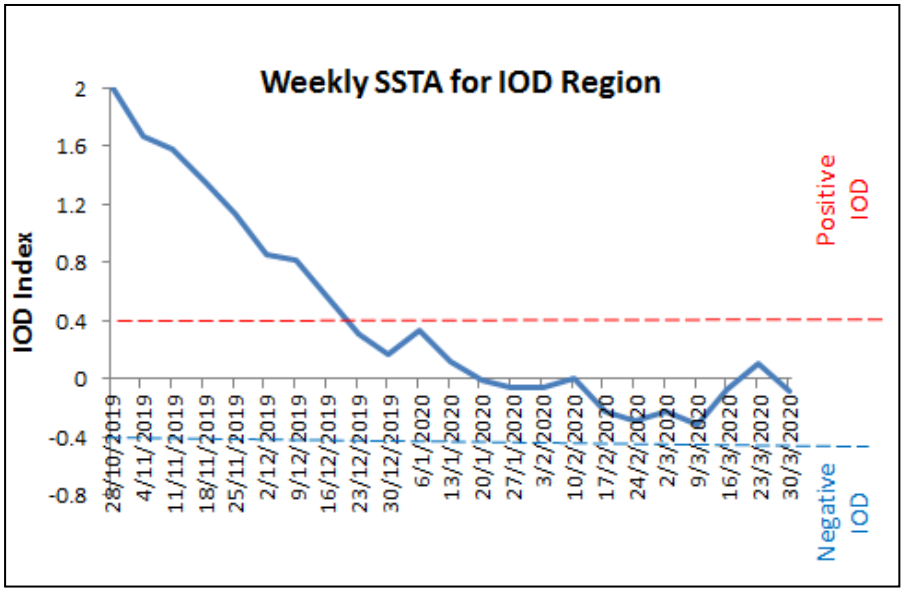

Figure 21: Weekly SSTA for IOD Region from November 2019 to March 2020

4.0 Conclusion

This report revealed that the onset and withdrawal date of NEM 2019/2020, respectively, were on 14 November 2019 and 18 March 2020. The onset date had fallen within the average onset date. Nonetheless, the withdrawal date according to Moten et al. (2014) strayed away from the average withdrawal date which is 16 May 2020. The withdrawal date on 18 March 2020 was chosen, considering that the synoptic features did not follow the NEMI index. The duration days of NEM 2019/2020 were short as compared to the average NEM period. The determination of the onset and withdrawal of the monsoon was only based on the zonal wind component which is not accurate. Therefore, the meridional wind component should be considered in the index. However, further studies to improve NEMI need to be carried out to suggest more robust index calculation.

The total surges during NEM 2019/2020 are 11. Three episodes of heavy rainfall were observed during this season which is in surge episode 4, 6, and 7. Overall, the other surges were declared as dry surge due to the non-existence of significant rainfall. Also, the impact of rainfall in Malaysia is relatively dry based on the anomaly average rainfall for December, January, and February. This condition was attributed to cross-equatorial wind flow over Malaysia caused by the position of the monsoon trough at the equator. Other than that, the cross-equatorial flow diverts moisture away from Malaysia to the Southern Hemisphere leading to enhanced convection in Sumatra and Java.

The summary in statistics of MS, ES, and MES during the Northeast Monsoon 2019/2020 and the climatology in Malaysia are depicted in **Table 5**.

Table 5: The statistics of Meridional Surges (MS), Easterly Surges (ES), and Mixed Surges (MES) during the Northeast Monsoon in Malaysia

	Climatology	**During NEM 2019/2020**
MS		
Earliest First Surges	1 October	5 November
Average First Surges	22 October	-
Late First Surges	20 November	-
Earliest Last Surges	24 December	27 February
Average Last Surges	25 February	-
Late Last Surges	28 March	-
Least No. of MS	5	3
Average No. of MS	11	-
Highest No. of MS	18	3
Average days per season	28 days	18 days
Average days per episode	3 days	6 days
ES		
Earliest First Surges	19 October	26 November
Average First Surges	17 November	-
Late First Surges	29 December	-
Earliest Last Surges	7 February	27 February
Average Last Surges	20 March	-
Late Last Surges	30 March	-
Least No. of ES	8	-
Average No. of ES	13	-
Highest No. of ES	22	-
Average days per season	38 days	53 days
Average days per episode	3 days	7 days
MES		
Earliest First Surges	4 November	28 November
Average First Surges	7 December	-
Late First Surges	26 January	-

Earliest Last Surges	6 January	28 November
Average Last Surges	10 February	-
Late Last Surges	23 March	-
Least No. of MS	1	-
Average No. of MS	5	-
Highest No. of MS	9	-
Average days per season	10 days	3 days
Average days per episode	2 days	3 days

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